

## **8. CHEMICAL PROCESS SAFETY**

This chapter presents the preliminary chemical process safety assessment for the Mixed Oxide (MOX) Fuel Fabrication Facility (MFFF). It describes the chemical processes, major chemicals affecting licensed material and hazardous chemicals produced from licensed material, chemical accident sequences and consequences, process safety information, and safety interfaces.

The preliminary chemical process safety evaluation provides reasonable assurance that the MFFF design provides adequate protection against chemical and radiochemical hazards related to the storage, handling, and processing of licensed material as required by 10 CFR Part 70. The preliminary analyses conducted to date indicate that no additional principal structures, systems, and components (SSCs) are required that are not already identified for control of radiological or other hazards, except as noted in Section 5.5.2.10.6.3. Further chemical process safety evaluation will be performed as part of the detailed design and will be included in the Integrated Safety Analysis (ISA) Summary submitted with the license application for possession and use of special nuclear material (SNM).

### **8.1 CHEMICAL PROCESS DESCRIPTION**

The MOX Fuel Fabrication Building and the Reagent Processing Building form the core group of buildings for plutonium polishing (i.e., aqueous polishing [AP] process) and MOX fuel fabrication (i.e., MOX processing [MP] process). The MOX Fuel Fabrication Building is a multifunctional reinforced-concrete structure containing all of the SNM handling, processing, and fuel fabrication operations. The building is comprised of three major functional, interrelated areas: the MP Area, the AP Area, and the Shipping and Receiving Area. The entire structure and the three component areas are designed for natural phenomena hazards (e.g., earthquakes, floods, tornadoes), as well as potential industrial-type accidents (e.g., load drop, fire) that could impact licensed materials. The Reagent Processing Building, located adjacent to the AP Area of the MOX Fuel Fabrication Building, provides space for storage and mixing of the chemical reagents used in the AP process. Chapter 11 provides detailed descriptions of the MFFF facilities and processes.

#### **8.1.1 Chemical Process Summary**

To meet commercial fuel purity specifications, a solvent extraction process is used to separate plutonium from gallium, americium, uranium, and other minor impurities. Polished plutonium oxide ( $\text{PuO}_2$ ) is used to produce MOX fuel. Chemical processes take place as part of the AP and MP processes, supported by chemical preparation in the Reagent Processing Building.

##### **8.1.1.1 Reagent Processing Building**

No radioactive materials or radiochemicals are stored, processed, or commingled in the Reagent Processing Building. The floor level of the Reagent Processing Building is slightly above grade and the building has a below-grade collection tank room that receives waste chemicals from the building. The Reagent Processing Building is divided into discrete rooms/areas to segregate chemicals and the associated equipment and vessels to prevent inadvertent chemical interaction. Safety showers and eyewash stations are provided at various locations throughout the facility in accordance with applicable OSHA standards. A loading dock at one end of the Reagent

Processing Building is used for unloading and transfer of chemical containers into and out of the building. Waste chemicals (included those resulting from spills) originating from the Reagent Processing Building are pumped from segregated waste collection tanks to portable containers for proper disposal in accordance with applicable requirements.

Most reagents (e.g., nitric acid, hydrogen peroxide, hydroxylamine nitrate [HAN], hydrazine hydrate, oxalic acid, sodium carbonate, diluent [C10-C13 isoalkane], nitrogen tetroxide, sodium hydroxide, zirconium nitrate, and tributyl phosphate [TBP]) are stored and solutions are prepared in the Reagent Processing Building for use in the AP Area. Nitrates of silver, aluminum, and manganese are stored and prepared in the AP Area. Liquid chemical containers are located inside curbed areas to contain accidental spills. Chemicals are transferred to the AP Area from the Reagent Processing Building via piping located in a concrete, below-grade trench between the two buildings.

Potential impacts of chemical accidents in the Reagent Processing Building on principal SSCs or personnel performing functions related to items relied on for safety (IROFS) are discussed in Chapter 5.

#### **8.1.1.2 Aqueous Polishing Process**

The AP process consists of 16 process units or systems (units symbols are indicated in parenthesis):

- Decanning Unit (KDA)
- Milling Unit (KDM)
- Recanning Unit (KDR)
- Dissolution Unit (KDB)
- Dechlorination and Dissolution Unit (KDD)
- Purification Cycle (KPA)
- Solvent Recovery Cycle (KPB)
- Oxalic Precipitation and Oxidation Unit (KCA)
- Homogenization Unit (KCB)
- Canning Unit (KCC)
- Oxalic Mother Liquor Recovery Unit (KCD)
- Acid Recovery Unit (KPC)
- Offgas Treatment Unit (KWG)
- Liquid Waste Reception Unit (KWD)
- Uranium Oxide Dissolution Unit (KDC)
- Sampling System (KPG).

The AP process is described in detail in Section 11.3.

#### **8.1.1.3 MOX Fuel Fabrication Process**

The MP process involves dry workshops (e.g., powder, pellet, and rod processing) and is described in detail in Section 11.2.

#### **8.1.1.4 Laboratory**

Chemical and physical analyses of samples from the MP and AP Areas are conducted in the laboratory. Analyses are required for manufacturing control, nuclear material management, quality control, and safety controls. Production sample analyses are performed at different stations consisting of gloveboxes, and transfers between stations are conducted manually (using a specific container or a vial in a vinyl double sleeve) or pneumatically. Several laboratory benches and fume hoods are provided for checking and distributing chemical reagents for different analytical processes. The laboratory is described in further detail in Section 11.11.

#### **8.1.2 Chemical Process Detail**

This section addresses the chemical process descriptions, the names and formulae of chemical reactants and products, and operating conditions. This section also identifies which chemicals come in contact with licensed materials, could impact operations with licensed materials, or are formed as by-products from chemical reactions with licensed materials. (Note that "hazardous chemicals produced from licensed materials," as defined in 10 CFR 70, do not include substances prior to process addition to licensed material or after process separation from licensed material.) The chemical process description at this stage of the design includes sufficient information to allow an understanding of the hazards associated with the chemical process.

##### **8.1.2.1 Reagent Chemicals Process**

Chemicals are received in various forms (solid, liquid, and gas) for use in the MFFF process. Most chemicals are stored in the Reagent Processing Building while some are stored in the AP Area or the MP Area. The various chemicals prepared and/or stored in these areas include the following:

- Solids
  - Reagent Processing Building – oxalic acid and sodium carbonate
  - AP Area – silver nitrate, manganese nitrate, plutonium dioxide, and uranium dioxide
  - MP Area – azodicarbonamide, zinc stearate, plutonium dioxide, and uranium dioxide
- Liquids
  - Reagent Processing Building – hydrazine hydrate, hydroxylamine nitrate (HAN), nitric acid ( $\text{HNO}_3$ ), tributyl phosphate (TBP), diluent (C10-C13 isoalkane), hydrogen peroxide, sodium hydroxide, hydrazine nitrate, and zirconium nitrate
  - AP Area – recovered nitric acid, aluminum nitrate solution, silver nitrate solution, manganese nitrate solution, and zirconium nitrate solution
  - MP Area - Isopropanol
- Gases
  - Reagent Processing Building – dinitrogen tetroxide ( $\text{N}_2\text{O}_4$ ) (stored in liquefied form)
  - Site – nitrogen, oxygen, hydrogen, argon, P10 (10% methane/90% argon), helium, and 95% argon/5% hydrogen
  - AP Area – nitrogen, oxygen, P10 (10% methane/90% argon), and 95% argon/5% hydrogen

- MP Area – nitrogen, hydrogen, argon, P10 (10% methane/90% argon), helium, and 95% argon/5% hydrogen.

Storage facilities in the Reagent Processing Building contain the following:

- Drums/tote tanks of the following reagents: 13.6N HNO<sub>3</sub>, TBP, diluent, HAN (1.9M), hydrazine hydrate (22% hydrazine in water), sodium hydroxide (10N)
- Cylinders of liquid N<sub>2</sub>O<sub>4</sub>
- Containers of hydrogen peroxide (30 wt %)
- Storage of material for dissolving solid reagents, including oxalic acid and sodium carbonate.

Tables 8-1a through 8-1e identify the expected chemicals received and distributed to the MFFF process. Chemicals and chemical mixtures in the process generally are used at lower concentrations than the reagent-grade chemicals stored in the Reagent Processing Building or AP Area.

#### **8.1.2.2 Aqueous Polishing Area Chemical Process**

Details on the chemical processes found in the AP area are provided in Section 11.3.

#### **8.1.2.3 MOX Processing Area Chemical Process**

The chemical processes in the MP area require the blending of uranium and plutonium oxides and the addition of poreformer and lubricant. Details on the MP Area chemical process are provided in Section 11.2.

#### **8.1.3 Process Chemistry**

The descriptive equations and other process chemistry information are provided in Section 11.3.

#### **8.1.4 Chemical Process Equipment, Piping, and Instrumentation**

Principal SSCs associated with chemical processing are identified in Chapter 5.

#### **8.1.5 Chemical Process Inventories**

The chemical inventory information in Tables 8-2a through 8-2d provides a summary of anticipated onsite inventories. Additional information associated with chemical inventories is provided in Section 11.3.

Common hazardous materials (e.g., vehicle fuel) and commonly used small quantities of solvents and gases are also used onsite. Specific inventories will be identified in the detailed design.

#### **8.1.6 Chemical Process Ranges and Limits**

Process ranges and limits are discussed in Section 11.3.

## **8.2 HAZARDOUS CHEMICALS AND POTENTIAL INTERACTIONS**

This section identifies the major chemicals stored and used at the MFFF, identifies potential interactions among these chemicals, and discusses potential unusual and unexpected reactions.

### **8.2.1 Chemicals**

Process chemicals used during normal operation are listed in Tables 8-1a through 8-1e. The tables are divided by plant area: Table 8-1a lists process chemicals present in the Reagent Processing Building; Table 8-1b lists the process chemicals present in the Aqueous Polishing Building; and Table 8-1c lists the chemicals present in the MOX Processing Building. Tables 8-1d and 8-1e identify the chemicals currently anticipated in the Laboratories and Gas Storage Area, respectively.

Maximum anticipated onsite chemical inventories are presented in Tables 8-2a through 8-2d. Table 8-2a identifies the major chemical inventories associated with tanks, vessels, and containers located in the Reagent Processing Building, Aqueous Polishing Building, and MOX Processing Building. Other smaller tanks, vessels, and containers within the Reagent Processing Building, Aqueous Polishing Building, and MOX Processing Building are not included in Table 8-2a since, for the purpose of chemical accident analyses, the chemical quantities are bounded by those values listed in Table 8-2a. Tables 8-2b, 8-2c, and 8-2d identify the chemical inventories currently anticipated in the Secured Warehouse (uranium dioxide), Laboratories, and Gas Storage Area, respectively.

Table 8-3 identifies significant reaction products and intermediate chemicals produced as a result of AP processing. There are no significant chemical reaction byproducts as a result of MP processing.

### **8.2.2 Chemical Interactions**

Human error or equipment malfunction could result in inadvertent chemical interactions and initiate hazardous reactions. General hazardous chemical characteristics and incompatibilities with the associated materials/process conditions are identified for AP and MP process chemicals in Table 8-4. Sampling of chemical reagents upon receipt, control of chemical preparation in accordance with operating procedures by trained personnel, proper handling and storage, and the proper selection of process materials of construction minimize the potential for unexpected chemical interactions. To mitigate the risk to principal SSCs associated with inadvertent chemical interactions, most chemical reagents for the AP process are prepared in the Reagent Processing Building and distributed to the AP Area.

Chemically induced explosion events originating within the MFFF, as well as those associated with support facilities, are discussed in Section 5.5.2.4. Hazards and operability studies (HAZOPs) and other evaluations will be prepared as part of the ISA during the detailed design to support the identification of other inadvertent chemical interactions. A complete chemical interaction evaluation will be provided in the license application for possession and use of SNM.

### 8.2.3 Unusual and Unexpected Reactions

The primary chemical reactions associated with AP processing are described in Section 11.3. Table 8-3 identifies normal reaction products and intermediate chemicals produced as a result of AP processing. There are no significant chemical reaction byproducts as a result of MP processing.

In general, AP chemical reactions produce the following by-products: carbon dioxide, carbon monoxide, chlorine, hydrogen, nitrogen oxides, nitrogen, nitric acid, oxygen, sodium chloride and water. Alkaline wastes containing decomposition products of TBP and other chemical by-products are produced in the Solvent Recovery Unit and processed in the waste processing unit. The following plutonium and uranium compounds are formed as process intermediates: plutonium nitrate, plutonium oxalate, and uranyl nitrate, in addition to polished plutonium oxide that results from AP processing.

Several additional hazardous compounds are produced in trace quantities or could be created from off-normal operations. These include the following: hydrazoic acid, azide salts, and plutonium (VI) oxalate. Off-normal process conditions could also lead to "red oil" formation and excessive exothermic reactions involving HAN and nitrous acid. Additional potential process hazards include the flammability of hydrogen generated through the radiolysis of hydrogenated materials, the explosive decomposition of high concentrations of hydrogen peroxide, and the use of a combustible solvent in the Purification Cycle. A description of these hazards and the controls necessary to reduce the associated risk are described in Sections 5.5 and 8.5.

Specific pathways leading to accidents involving these hazards resulting from process failures or personnel errors will be identified and evaluated during hazards and operability studies (HAZOPs) and other evaluations as part of the ISA during the detailed design.

## 8.3 CHEMICAL ACCIDENT SEQUENCES

According to 10 CFR Part 70, hazardous chemicals produced from licensed materials are identified as "substances having licensed material as precursor compound(s) or substances that physically or chemically interact with licensed materials; and that are toxic, explosive, flammable, corrosive, or reactive to the extent that they can endanger life or health if not adequately controlled. These include substances commingled with licensed material, but do not include substances prior to process addition to licensed material or after process separation from licensed material."

This section provides the methodology and results for the evaluation of chemical consequences that are associated with a release of hazardous chemicals produced from licensed materials as defined by 10 CFR Part 70. The radiological effects of these events and the effects that chemical-related events may have on the safety of radiological material are discussed in Chapter 5.

Hazards that involve only chemicals and that do not affect radiological safety will be addressed in accordance with applicable Occupational Safety and Health Administration (OSHA)

requirements. Non-routine work safety will be addressed through the use of work authorization and task analysis or activity-based hazard analysis.

### 8.3.1 Chemical Accident Sequence Bases

To identify the physical processes that control the nature and rate of vapor generation and release, a range of initial conditions is considered, as well as the failure modes of storage containers and associated systems. The following release scenarios are addressed:

- Leaks and ruptures involving equipment vessels and piping
- Evaporating pools formed by spills and tank failures
- Flashing and evaporating liquefied gases from pressurized storage.

Explosion events that could result in the release of hazardous chemical vapors are addressed in Sections 5.5 and 8.5. The chemical consequences are based on bounding analyses. More detailed accident sequences will be developed in the ISA as necessary.

### 8.3.2 Unmitigated Sequences

In lieu of a mechanistic calculation of the release, a conservative bounding release model is used to determine the consequences to the site worker (100 meters) and members of the public at the Controlled Area Boundary (CAB) (5.1 miles). Releases are modeled to occur using the total material at risk from the largest single tank or container. Furthermore, no credit is afforded to process equipment installed to remove/scrub some of the potentially released chemicals prior to release from the MFFF.

### 8.3.3 Estimated Concentrations

Estimates of hazardous chemical concentrations include techniques, assumptions, and models that are consistent with industry practice, are verified and/or validated, and follow the guidance on atmospheric and consequence modeling found in NUREG/CR-6410, *Nuclear Fuel Cycle Accident Analysis Handbook*.

Several different methodologies were applied to the performance of chemical consequence analyses based on the nature of the chemical and the location of the receptor. For calculating airborne concentrations at the CAB involving evaporative releases, the more conservative release rate from the following two separate evaporation models (Kawamura and Mackay 1987, equation 8.3-1 and NUREG/CR-6410, Appendix B, equation 8.3-2) was used as input to the Areal Locations of Hazardous Atmospheres (ALOHA) computer code. These evaporation models, applicable to liquids released at ground level in a pool, are as follows:

$$E = A * K_M * (MW_m * P_v / (R * T)) \quad (8.3-1)$$

where

E = evaporation rate (kg/sec)

A = area of the evaporating puddle (m<sup>2</sup>)

K<sub>M</sub> = mass transfer coefficient (m/sec)

$MW_m$  = molecular weight of the material of interest (kg/kmol)

$P_v$  = vapor pressure (Pa)

$R$  = the gas constant (8314 J/kmol K)

$T$  = ambient temperature (K)

$$Q_o = k_g \cdot A_p \cdot p_v \cdot M / (R \cdot T_p) \quad (8.3-2)$$

where

$Q_o$  = rate of evaporation (kg/sec)

$k_g$  = mass transfer coefficient (m/sec)

$A_p$  = area of the pool ( $m^2$ )

$p_v$  = vapor pressure (Pa)

$M$  = molecular weight of the material of interest (kg/kmol)

$R$  = the gas constant (8314 J/kmol K)

$T_p$  = temperature of the pool (K)

The mass transfer coefficient is dependent on the air speed over the pool or puddle. For an unmitigated release outdoors, an air speed of 2.2 meters/second is used, which is consistent with 95% "worst-case" meteorological conditions at SRS. For a mitigated release inside the MFFF, a much lower air speed of 0.1 meters/second is used, which is consistent with the maximum volumetric air flow rate through the room in which the pool or puddle is located.

Results from the ALOHA code were then extrapolated to obtain airborne concentrations at the CAB. ALOHA was originally developed by the National Oceanic and Atmospheric Administration for on-scene commanders at a spill site for emergency response applications. In light of this application, and because of the likelihood of changes in atmospheric conditions after a short time, an execution time of one hour is "hardwired" into the code. Assuming worst case meteorological conditions (i.e., wind speed of 2.2 meters per second), a dispersing chemical release can only travel 7.9 km (4.9 miles) in an hour, and cannot reach the CAB in that time. Therefore, the maximum concentration of the released chemical at the CAB is estimated by extrapolation of the maximum ALOHA concentrations for runs at distances of 7.9 km (4.9 miles) and less using curve-fitting techniques.

To calculate airborne concentrations at the CAB for other chemicals with low solute concentrations or low vapor pressures, source terms were generated using a five-factor formula involving the product of the material at risk (MAR), damage ratio (DR), airborne release fraction (ARF), respirable fraction (RF), and leak path factor (LPF). These values were then multiplied by the CAB atmospheric dispersion factor ( $\chi/Q$ ) calculated by the MACCS2 (MELCOR Accident Consequence Code System for the Calculation of the Health and Economic Consequences of Accidental Atmospheric Radiological Releases) code to obtain an airborne concentration at the CAB.

For evaporative releases affecting the site worker, the more conservative release rate from the two separate evaporation models identified above was selected and multiplied by the 100-meter atmospheric dispersion factor ( $\chi/Q$ ) calculated by the ARCON96 (Code System to Calculate



Atmospheric Relative Concentrations in Building Wakes) code to obtain an airborne concentration. To calculate airborne concentrations for other chemicals affecting the site worker, source terms were generated using the same five-factor formula described above. These values were then multiplied by the 100-meter atmospheric dispersion factor ( $\chi/Q$ ) from the ARCON96 code. For chlorine and NO<sub>x</sub> releases, release rates were obtained from chemical flow balances for the units where these chemicals are generated from SNM. The applied release rates do not credit the process scrubbers installed to remove a majority of these chemical by-products.

### 8.3.3.1 Dispersion Modeling

ALOHA is a time-dependent model that treats neutral or heavy gases and a variety of time-dependent sources, including broken pipes, leaking tanks, and evaporating puddles, modeled in consideration of atmospheric turbulence, entrainment, advection, and gravitational spreading. It is the preferred model for calculating chemical concentrations at distances approaching the CAB. The ALOHA computer code was verified and validated prior to its use for the evaluation of MFFF bounding chemical release consequences.

There are two discrete dispersion models in ALOHA: *Gaussian* and *heavy gas*. The Gaussian model was used for determining chemical concentrations at the CAB involving evaporative releases, as it yields conservative results for the applicable scenarios. The Gaussian model predicts dispersion of *neutrally buoyant gases* that have about the same density as air. Wind and atmospheric turbulence move the released gas through the air so that an escaped cloud is blown downwind, with "turbulent mixing" causing it to spread out in the crosswind and upward directions. A graph of gas concentration within any crosswind slice of a moving pollutant cloud looks like a bell-shaped curve, high in the center (where concentration is highest) and lower on the sides (where concentration is lower). At the point of a release, the pollutant gas concentration is very high, since the gas has not diffused very far in the crosswind and upward directions. A concentration graph in a crosswind slice of the cloud close to the source is a spike. As the pollutant cloud drifts farther downwind, it spreads out and the "bell shape" becomes wider and flatter.

MACCS simulates the accidental release of a plume of radiological materials to the atmosphere and estimate consequences associated with the release. The dispersion model in MACCS2 treats atmospheric transport and dispersion of material utilizing a Gaussian plume model with Pasquill-Gifford dispersion parameters and can be used for chemical as well as radiological consequence assessments. The code does not model dispersion close to the source (less than 100 meters from the source).

The dispersion model in the ARCON96 code is used for distances close to the release point. ARCON96 empirically accounts for building wake effects occurring under all meteorological conditions and plume meander, which occurs during light-wind stable conditions. It is the only model that is available that accounts for both the vertical and horizontal components of building wake effects and the effects of plume meander. Plume meander occurs under very stable light wind speed conditions (e.g., F stability class with wind speed of 2.2 meters/second). The magnitude of plume meander decreases with distance from the release, higher wind speeds, and more unstable conditions. All of the meander factor decays within 1 kilometer. The building

wake effect also decays as the distance from the release location increases, but it increases with wind speed and more unstable conditions. The faster the wind speed, the larger the aerodynamic effect on the wind field of the building structure.

### **8.3.4 Concentration Limits**

Chemical concentration limits are required to be established to evaluate the potential consequences to the public and to workers for an accidental release of chemicals. Three levels, High (H), Intermediate (I), and Low (L), based on 10 CFR §70.61, are used to define these limits.

Limits are based on Acute Exposure Guideline Level (AEGL) values and Emergency Response Planning Guideline (ERPG) values. Since AEGL and ERPG values are not established for all MFFF chemicals, Temporary Emergency Exposure Limits (TEELs) have been adopted for use in chemical consequence analysis. TEELs were adopted by the U.S. Department of Energy (DOE) Subcommittee on Consequence Assessment and Protective Action (SCAPA). The SCAPA-approved methodology was used to obtain hierarchy-derived TEELs.

The original TEEL methodology used only hierarchies of published concentration limits (i.e., Permissible Exposure Levels [PELs] or Threshold Limit Values – Time-Weighted Averages [TLV-TWAs], Short-Term Exposure Levels [STELs], and Immediately Dangerous to Life and Health [IDLH] values) to provide estimated values approximating ERPGs. The expanded method for deriving TEELs also includes published toxicity data (TD<sub>LO</sub>, TC<sub>LO</sub>, LD<sub>50</sub>, LC<sub>50</sub>, LD<sub>LO</sub>, and LC<sub>LO</sub>). Hierarchy-based values take precedence over toxicity-based values, and human toxicity is preferred to animal toxicity data. Subsequently, default assumptions based on statistical correlation of ERPGs at different levels (e.g., ratios of ERPG-3s to ERPG-2s) were used to calculate TEELs where there were gaps in the data. The TEEL hierarchy/toxicity methodology was used to develop community exposure limits for over 1,200 chemicals to date. The following are the TEEL definitions:

- **TEEL-0** – The threshold concentration below which most people will experience no appreciable risk of health effects.
- **TEEL-1** – The maximum concentration in air below which it is believed nearly all individuals could be exposed without experiencing other than mild transient adverse health effects or perceiving a clearly defined objectionable odor.
- **TEEL-2** – The maximum concentration in air below which it is believed nearly all individuals could be exposed without experiencing or developing irreversible or other serious health effects or symptoms that could impair their abilities to take protective action.
- **TEEL-3** – The maximum concentration in air below which it is believed nearly all individuals could be exposed without experiencing or developing life-threatening health effects.

TEEL values for MFFF chemicals are listed in Table 8-5. Chemical consequence categories for comparison to 10 CFR §70.61 are provided in Table 8-6.

## 8.4 CHEMICAL ACCIDENT CONSEQUENCES

### 8.4.1 Analysis

Consequence analysis follows the guidance found in NUREG/CR-6410. Conservatism is embedded in the source term and the ground-level release models.

The analysis to determine the effects at the CAB to the public is based on the following assumptions:

- A wind speed of 2.2 meters per second and F stability class, indicative of 95% "worst-case" meteorological conditions at SRS;

Note: The 95% wind speed of 2.2 meters per second was calculated from the 95%  $\chi/Q$  value from the ground-level release application of the ARCON96 code applied at a distance of 100 meters. The ARCON96 code was driven by five years of hourly SRS meteorological data. The calculation assumes an F-stability class to quantify  $\sigma_y$  and  $\sigma_z$ . The 100-meter distance is selected because it represents the site worker location. This technique yields a site-specific 5% meteorological condition (F stability class @ 2.2 m/second wind speed) that is more applicable than adopting the 40 CFR §68.22 meteorology, which is generalized for the entire United States.

- A wind direction that transports the puff kernel and/or plume centerline directly over the receptor of concern (conservative), thereby eliminating any crosswind dispersion;
- An ambient temperature of 25°C (77°F) and 50 percent humidity; representative of late-spring to early-autumn conditions;
- A ground level release (conservative);
- No mechanical or buoyancy plume rise (conservative);
- A rural (i.e., flat terrain) topography (conservative);

Note: The forest canopy morphology at SRS is more accurately characterized as urban terrain relative to atmospheric turbulence intensity.

- Neutrally buoyant gas model (conservative).

Note: Heavy gas models result in lower downwind concentrations, which are less conservative. This is due to density differences (e.g., Colenbrader model within ALOHA) that entrain clean air within the sides of the pancake-like dense gas plume.

These bounding assumptions envelop uncertainties inherent in realistic analyses.

Data in Tables 8-2a through 8-2d were used to perform chemical consequence analyses associated with the largest credible unmitigated spill or loss of containment accident involving each of these chemicals. Airborne concentrations were calculated at distances correlating to the

site worker (100 meters) and members of the public (CAB). These concentrations were then compared to the TEELs presented in Table 8-5. From this comparison, a consequence category was established (low, intermediate, high) using the guidance outlined in Table 8-6. These consequence categories correspond to those identified in 10 CFR §70.61.

It should be noted that for the chemicals identified in Tables 8-2a through 8-2d whose onsite inventory is not yet established or is based on preliminary data, the analysis is based on a conservative projection for that chemical. Nonhazardous chemicals and gases identified in Table 8-2d were not evaluated. Except for oxygen, exposure to these gases poses an asphyxiant hazard only. Gas concentrations at asphyxiation levels are not credible at the distances corresponding to the CAB. Gas concentrations at asphyxiation levels may be credible for very large leaks at the distance corresponding to the site worker. Oxygen has no established toxicity limit.

Results of the chemical consequences calculation indicate that for all chemicals to which the requirements of 10 CFR §70.61 apply, unmitigated consequence categories fall within the acceptable range for site workers and members of the public, with the exception of those releases described in Section 5.5.2.10.6.3. Thus, no principal SSCs are required for the protection of site workers and members of the public, except as identified in Section 5.5.2.10.6.3.

Nitric acid leaks or spills in the Aqueous Polishing area of the MFFF were also modeled at temperatures up to the boiling point of nitric acid. The evaporation rate of the nitric acid was calculated utilizing an indoor wind speed of approximately 0.01 meters/second. The consequences of these nitric acid leaks or spills over the full range of temperatures were calculated to be low for the site worker and members of the public.

Uranium dioxide powder releases from the Secured Warehouse, including evaluations of fire and seismic events, are calculated to be low consequence events for the site worker and members of the public. More detailed analyses based on final design and operations are in progress to confirm the results for the site worker. If features such as combustible load controls are required to meet the criteria for the site worker, the features will be identified as IROFS in the ISA.

For the facility worker, the chemical consequences are estimated to be low, except as identified in Section 5.5.2.10. Calculations will be performed for the ISA to confirm this estimate. Principal SSCs have been defined for radiological events, and these SSCs are expected to be applicable to process units where chemicals mix with radiological material, except as identified in Section 5.5.2.10. Furthermore, for chemical exposures that could affect the facility worker in performing a required safety function in the Emergency Control Room, the Emergency Control Room Air Conditioning System is identified as a principal SSC (see Section 5.5.2.10). In the unlikely event that the ISA performed as part of detailed design identifies events that are not bounded, additional SSCs will be identified to ensure that chemical risks are acceptable.

#### **8.4.2 Latent Impacts**

The risk of cancer can be estimated by combining information about the carcinogenic potency of a chemical and exposure to the substance. For potential carcinogens, risks are estimated as the incremental probability of an individual cancer over a lifetime as a result of exposure to the potential carcinogen. The carcinogenic risks are estimated by multiplying the cancer toxicity

parameter (potency slope factor), which is the upper 95% confidence limit of the probability of a carcinogenic response per unit intake over a lifetime of exposure. The two important parameters or measures for describing carcinogenic effects are the individual cancer risk and the estimated number of cases (i.e., the cancer burden). Latent risk, including mutagenic and teratogenic effects, will be covered in the license application for possession and use of SNM.

### **8.4.3 Uncertainty**

Estimates of risks are often accompanied by uncertainty because of the complexity of the postulated scenarios and physical models used to describe them. At this stage of the design, conservative models were utilized for the chemical releases with the intent to bound any anticipated uncertainty. Uncertainties associated with more detailed consequence analyses performed for the ISA will be described in the license application for possession and use of SNM.

## **8.5 PROCESS SAFETY INFORMATION**

### **8.5.1 Process Safety Controls**

The MFFF includes three basic facilities:

- **Reagent Processing Building** – This building is the front end of the process, where reagents for the process are prepared and transported to the processing units.
- **AP Area** – This area is the location of the primary chemical processing (Aqueous Polishing).
- **MP Area** – This area contains the manufacturing unit for the production of fuel assemblies (MOX Process).

Each of these facilities has control requirements that are incorporated into the overall design of the control system for process safety control. The control system will be designed to be available and reliable.

Reagents are stored and chemical mixtures are prepared in the Reagent Processing Building and in the reagent storage area of the AP Area. The AP facility is broken down into process functional units, which are functionally made up of one or more subunits performing elementary unit operations. The breakdown into functional units allows each unit to be operated relatively independently of other functional units.

Process storage and operation conditions are controlled to prevent unintended exothermic and potential autocatalytic reactions in the Reagent Processing Building and AP Area. Autocatalytic and exothermic reactions of chemicals are prevented through control of the process parameters (e.g., reactant concentration, temperature, catalyst concentration in solution, and pressure) that affect the reactions.

Significant chemical-related risks and associated design bases information are discussed in the following sections.

### 8.5.1.1 Hazards Associated with Hydrogen Gas

This section discusses the hazards associated with hydrogen as used or produced in the various processes within the MFFF. The following text discusses the flammable and explosive nature of hydrogen and provides the basis for the limits to be applied in the design of the processes using or producing hydrogen to assure the risks associated with hydrogen hazards satisfy the performance requirements of 10 CFR §70.61. The subsections that follow this section discuss the specific hazards identified in Section 5.5 associated with hydrogen (i.e., hazards associated with hydrogen-argon mixture in sintering furnace, radiolysis, and electrolysis).

#### Flammability Phenomena

Hydrogen is flammable over a wide range of concentrations in air. The values typically quoted are for concentrations of hydrogen in air at standard atmospheric temperatures and pressures (i.e., 4% through 74% by volume of hydrogen). The leanest mixture that burns completely is 9%; however, hydrogen flames will propagate in the upward direction at concentrations as low as 4% because of the high diffusivity of hydrogen. The flammability limits of hydrogen have been found to be consistent for gas pressures below 1 atm up to 100 atm.

The flammability limits are affected by temperature and by various concentrations of inert diluents, see Figure 8.5.1.1-1 for gas mixtures containing argon. Increasing the temperature tends to lower the lower flammability limit (LFL) and raise the upper flammability limit (UFL) for hydrogen in air, until the spontaneous ignition temperature is reached. At that point any amount of hydrogen coming into contact with oxygen burns with a slow flame (less than 1 m/s at less than 8% H<sub>2</sub> in air). Increasing the temperature of a mixture of pure hydrogen in air will cause the LFL to decrease from 9 to 5.4%, and the UFL to increase from 74 to 88%. This effect is different when hydrogen is diluted with an inert gas such as argon.

As shown in Figure 8.5.1.1-1, flammable mixtures of hydrogen in air can be made nonflammable by the addition of enough inert gas, such as argon, provided sufficient controls are placed on the environment in which the mixed gas is used. Different diluents have different levels of inerting efficiency which must be accounted for in evaluating the potential risks for creating explosive mixtures.

#### Explosion Phenomena

Hydrogen gas mixtures can become explosive if a sufficient amount of fuel and oxidant is distributed throughout the mixture while the mixture is not exposed to an ignition source or it is below the spontaneous ignition temperature. Even if the mixture is exposed to an ignition source or raised to high enough temperature, the mixture will only ignite and explode under certain conditions. The explosiveness of the mixture depends on the gas concentration, temperature, pressure (i.e., the flammability limits), the container surface conditions and the container size. Gas concentrations below or above the LFL and UFL are nonexplosive. Because the flammability limits vary with temperature and gas composition, these variables are considered when choosing the applicable lower and upper explosive limits (the LEL and UEL).

Outside of the sintering furnace in the BMP and BAP, the MFFF intends to control combustible gas concentrations to levels below 50% of the LFL to ensure that the LEL is not exceeded and to

prevent explosions in the BMP and BAP. Inside of the sintering furnace, the MFFF intends to control the combustible gas concentrations to levels above the UFL at high temperatures, prevent or limit the introduction of air or other oxygen sources into the furnace, and to provide enhanced administrative controls during startup and shutdown of the furnace to ensure that the supply of combustible gas is stopped or the furnace is purged of combustible gases whenever the furnace is offline and prior to energizing the resistor heaters.

Explosions due to lean hydrogen concentrations below 8% in air will result in a peak pressure rise slightly above 1 bar (14.5 psi) because the low H<sub>2</sub> concentration does not allow downward propagation of the flame. At slightly higher concentrations of 9 to 10% H<sub>2</sub> (i.e., above the downward lower flammability limit) the peak pressures may be close to 3 to 4 bar (44 to 58 psi). The hydrogen concentration and temperature also play strong roles in determining whether the mixtures burn or explode. Thus, physical structures that mitigate or contain potential explosions are designed with these limits in mind.

Besides increasing the temperature of a combustible hydrogen mixture to above its spontaneous ignition temperature, the mixture can be ignited by a weak spark, such as one caused by the discharge of static electricity from a human body; open flames; hot surfaces or matches. Ignition of a gas mixture can result in the generation of a variety of different combustion regimes ranging from slow flames to detonations. Under certain conditions after ignition, slow flame fronts may be accelerated and transformed into detonations by the phenomenon of flame acceleration (FA) and deflagration to detonation transition (DDT). The conditions necessary to accelerate a flame to detonation are specific to the properties of the burned and unburned gas mixture and the physical layout and dimensions of the containment structure. Explosions may be prevented by controlling critical dimensions in the containment structure or by preventing the conditions necessary to sustain combustion or initiate ignition. Because of the complexity of the internal structures of the sintering furnace, the MFFF intends to prevent these types of explosions by controlling the conditions necessary to support combustion or initiate ignition.

#### Hydrogen Formation by High Temperature Reactions

Hydrogen can be formed at high temperatures by reactions with burning metals in which the oxygen atoms in the water are stripped off by unoxidized metal, thus releasing free hydrogen atoms. Hydrogen explosions in furnaces processing certain reactive metals (especially titanium) have been reported as a result of this reaction. The sintering furnace only processes a mixture of oxidized forms of uranium and plutonium. Therefore, any water that could come into contact with these oxides from excessive humidity in the process gas will only form steam and is not expected to become dissociated into free hydrogen. Explosions caused by increasing the hydrogen content of the process gas by this mechanism are thus precluded. Chapter 5.5.2.4.6.2 discusses the hazards involved with steam overpressure events.

##### **8.5.1.1.1 Argon-Hydrogen Mixture in Sintering Furnace and Hydrogen Storage**

A mixture of argon and hydrogen gas is used in the sintering furnace to provide the required atmosphere for pellet sintering. The gases are mixed outside of the MFFF building in the proper proportion and transferred to the pellet sintering areas via facility piping. Inherent with the use of hydrogen are the associated hazards of fire and explosion. These hazards are present at the

gas storage/mixing area, sintering furnace area, furnace gloveboxes and airlocks, sintering furnace exhaust and associated HVAC system, and the sintering furnace itself. Control of the hazards associated with hydrogen in these areas is discussed in the following paragraphs.

Fire and explosion events are prevented in the sintering furnace area, furnace gloveboxes and airlocks, sintering furnace exhaust, and associated HVAC system by the process safety control subsystem. The process safety control subsystem prevents the formation of flammable mixtures of hydrogen. The design basis for this control is fifty percent of the lower flammability limit (LFL) of hydrogen in air. Fifty percent of the LFL will not be exceeded during normal or off-normal conditions. The LFL is considered the safety limit, while twenty five percent of the LFL is the expected setpoint at which necessary control actions are initiated during normal operations. Actual setpoints will be determined as part of final design.

Fire and explosion events are prevented in the sintering furnace by the use of design features and procedures (administrative controls) that prevent the formation of flammable mixture of hydrogen in air. The basis for these engineered and administrative controls is NFPA 86C, *Industrial Furnaces Using a Special Processing Atmosphere*. As stated in Chapter 7.0, Fire Protection, fire safety for the sintering furnace is in accordance with the applicable requirements of NFPA 86C-1995.

The design bases of PSSCs associated with fire and explosion at the facility gas storage area (external events) are discussed in Section 11.1.7.

#### **8.5.1.1.2 Hydrogen Production due to Radiolysis**

Radiolysis is the process of hydrogen gas production by radiolytic dissociation of hydrogenous materials. Within the MFFF process, the hazards associated with radiolysis are present in some AP processes and in some waste drums. The potential for hydrogen production in the MOX process is low due to the negligible quantity of hydrogenous materials.

The design bases associated with the control of the hazards associated with hydrogen gas is in accordance with standard NFPA practices. The lower flammable limit (LFL) is considered the safety limit. This is the value at which an event may occur because the hydrogen concentration may be flammable. Fifty percent of the LFL is the design basis value. This is the value that will not be exceeded during normal or off-normal conditions. Twenty-five percent of the LFL is the projected setpoint. This is the value used to design the process and as necessary, is used to initiate control actions during normal operations.

In the AP processes, the risk associated with radiolysis is mitigated by maintaining adequate dilution airflow and ensuring an exhaust path exists. Calculations will be performed as part of detailed design to determine appropriate air flow rates and summarized in the ISA. Should normal airflow be lost to an AP process vessel, emergency scavenging air will be provided as described in Section 11.9. These airflow rates will ensure that 50 percent of the LFL is not exceeded during normal or off-normal conditions.

Hydrogen production and accumulation may occur in the waste and byproducts, such as contaminated organic waste or organic-additive-bearing waste containing significant amounts of plutonium, scraps in transuranic (TRU) waste containers, and other liquid waste. Where this



may become a hazard, the containers are equipped with a filtered vent system that limits hydrogen accumulation by providing an exhaust flow path while maintaining confinement of radioactive materials.

#### **8.5.1.1.3 Hydrogen Production by Electrolysis**

The dissolution unit and the dechlorination and dissolution unit utilize a catholyte loop in which nitric acid is used to dissolve plutonium oxide. This electrolytic dissolution process introduces the risk of generating hydrogen gas.

The design bases associated with the control of the hazards associated with hydrogen gas is in accordance with standard NFPA practices. The LFL is considered the safety limit, the value at which an event may occur because the hydrogen concentration may be flammable. Fifty percent of the LFL is the design basis value. This is the value that will not be exceeded during normal or off-normal conditions. Twenty-five percent of the LFL is the target setpoint. This is the value used to design the process and as necessary is used to initiate control actions during normal operations. Specific setpoints will be developed in accordance with the codes and standards described in Section 11.6.7 to ensure the design basis value is not exceeded.

The production of hydrogen during electrolysis is a function of the nitric acid normality. As described in Section 5.5.2.4, the normality of the nitric acid will be maintained sufficiently high to ensure that the off-gas is not flammable. Calculations will be performed as part of detailed design and summarized in the ISA to determine the appropriate nitric acid limits. These limits will ensure that 50 percent of the LFL is not exceeded during normal or off-normal conditions.

#### **8.5.1.2 Solvent Related Hazards**

Some units within the AP process are fed with solvent. The potential for solvent related fires and explosions exists due the possible attainment of a flammable/explosive mixture in the gaseous phase due to excessive heating.

As described in section 5.5.2, a combination of IROFS will be in place to ensure that explosive conditions associated with solvent vapors are prevented from occurring. These IROFS will include controlling the temperature of solutions containing solvents, minimizing the potential ignition sources, and providing an exhaust path for dilution of vapors.

#### **8.5.1.3 Hydroxylamine Nitrate (HAN) and Hydrazine (N<sub>2</sub>H<sub>4</sub>) in Nitric Media**

The Aqueous Polishing (AP) process uses a mixture of hydroxylamine nitrate (HAN) and nitric acid (HNO<sub>3</sub>) during the extraction step of the plutonium purification unit (KPA) to strip plutonium from the solvent after removal of americium and gallium. HAN has a number of advantages as a plutonium reductant. It is nonmetallic, it is readily decomposed to innocuous products by heating, the gaseous reaction products – nitrogen (N<sub>2</sub>), nitrous oxide (N<sub>2</sub>O), and water (H<sub>2</sub>O) – contribute to minimization of the volume of solid wastes produced, and it possesses the proper Pu (IV) to Pu (III) reduction attributes. However, due to the potential for HAN to undergo an autocatalytic reaction with nitrous acid under certain conditions, the use of HAN in the AP Process introduces an explosion/overpressure hazard.

Experience and insights gained from previous accidents involving HAN and experimental data from the Hanford and Savannah River sites are utilized in conjunction with La Hague Plant experience to assist in the determination of safe operating conditions for the storage and the handling of HAN, hydrazine and nitric acid.

The HAN-nitric acid system is a complex multi-parametric system involving the interdependence of the following four parameters:

- Chemical concentration of each reactant
- Molar ratio of nitric acid to HAN
- Temperature of the mixture
- Concentration of metal ion catalysts.

A general feature that has characterized many of the previous accidents with HAN mixtures without hydrazine is the inadvertent increase of solution temperature and/or concentration of or an inadvertent acid addition to these solutions. Experimental results indicate that high nitric acid concentrations or the presence of impurities (such as metal ions) increase the likelihood of the initiation of an autocatalytic reaction. Furthermore, for systems without metal catalyst, a trend of decreasing the autocatalytic reaction temperature threshold when increasing the nitric acid to HAN ratio has been found. Maintaining low nitrous acid concentrations has been indicated as important to storage and use of HAN, with respect to autocatalytic reactions. Previous attempts to characterize the stability of a system have examined both experimental and accident conditions in which the concentrations of nitric acid and HAN have increased. In these systems the energy liberated as a result of an autocatalytic reaction also increases as a function of the original energy content of the solution and the initial concentrations of HAN.

To understand the behavior of systems comprised of HAN, hydrazine, plutonium and metal ions with nitric acid, the various associated reactions are modeled. In this manner the kinetic rates for reactions governing production and consumption of nitrous acid are used to describe the stability of the system under normal, abnormal, and accident conditions. The chemical reactions that govern the solutions that may contain HAN include:

- Plutonium (IV) reduction by HAN
- Plutonium (IV) reduction by Hydrazine
- Plutonium (III) Re-oxidation
- HAN reaction with nitrous acid
- Hydrazine reaction with nitrous acid
- Catalyzed Nitrous Reactions with Metal Ions

Additional discussion of the safety strategies and specific controls associated with control of these reactions is found in Section 5.5.

#### **8.5.1.4 Hydrogen Peroxide**

A 35 wt % hydrogen peroxide solution is received and diluted to 10 wt % for use in the Dissolution Unit. Explosive vapors can be produced if the concentration of the hydrogen peroxide solution exceeding 75 wt % is boiled. As described in Section 5.5.2.4, chemical safety controls have been identified as the principal SSC to ensure that the explosive concentration of hydrogen peroxide does not occur at the MFFF. This principal SSC verifies through sampling that the specification and dilution of the reagent hydrogen peroxide concentration before use in the process is below the explosion limit. There are no processes in the MFFF that can increase the hydrogen peroxide solution concentration.

#### **8.5.1.5 TBP – Nitrate (Red Oil)**

##### **8.5.1.5.1 Background**

The degradation of TBP and subsequent oxidation of the associated by-products by nitric acid introduces the risk of a runaway reaction and associated over-pressurization event due to the exothermic property of the reactions and the off-gases produced. This risk exists in process units within the AP Process that may contain these constituents and simultaneously is subject to high temperatures (i.e., Acid Recovery Unit, Oxalic Mother Liquor Recovery Unit, Purification Unit, and Solvent Recovery Unit).

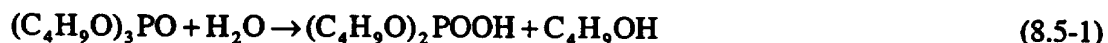
The term “red oil” has been used since two incidents occurred in 1953, one at Hanford and another at Savannah River, involving rapid chemical decomposition reactions that over-pressurized semi-works or pilot-plant evaporators. In a broad sense, red oil is any unstable organic-based material that forms or accumulates during an operation at high temperature and progresses, as the temperature increases, to a decomposition reaction yielding gaseous products and heat. The material may be degraded organic reaction products (such as nitrated or oxidized diluent or compounds consisting of butyl groups from TBP) or an organic-nitrate complex (such as a plutonium adduct). Examination of the residue remaining after the incidents identified a red-colored organic phase containing uranium, TBP, nitrate, and organic material derived from the diluent. The red color probably resulted from the nitration of relatively unstable constituents in the diluent, and it is believed these diluent degradation products may have also contributed to the event sequence. Once decomposition started and the temperature increased, however, the major reactants are thought to have been adducts, TBP, and associated by-products from the hydrolysis reaction.

##### **8.5.1.5.2 Chemical Reactions**

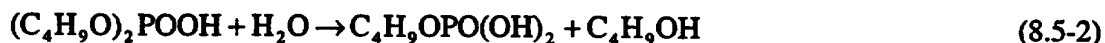
The degradation of TBP may proceed by the following mechanisms:

- **Acid Catalyzed Hydrolysis**

TBP, being an ester of phosphoric acid ( $\text{H}_3\text{PO}_4$ ), is likely to undergo ready hydrolysis. The reaction produces both butyl alcohol and dibutyl phosphate (DBP) as given by equation 8.5-1:

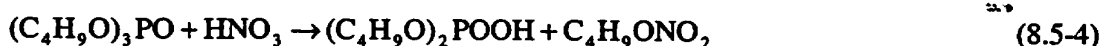


Further hydrolysis leads to the formation of monobutyl phosphate (MBP) and, ultimately, phosphoric acid as given by equations 8.5-2 and 8.5-3:



- **Dealkylation**

TBP may also undergo dealkylation with nitric acid as given by equation 8.5-4:



- **Pyrolysis**

When no water is present and the temperature goes above 150°C, TBP can undergo a pyrolysis reaction producing phosphoric acid and three molecules of butene, which is highly volatile and flammable, as presented in equation 8.5-5:



As noted above in the hydrolysis and dealkylation reactions, the degradation of TBP may form butanol and butyl nitrate. The butanol formed via the hydrolysis of TBP, DBP, and MBP may subsequently undergo nitration to form butyl nitrate. Subsequent oxidation of butyl nitrate by nitric acid leads afterwards to the formation of butyric acid, propionic acid, and acetic acid. Each of these respective degradation mechanisms is identified in Figure 8.5-2, and the degradation products are defined in Table 8-8.

In addition to the chemical degradation of TBP, radiolysis also creates a mechanism by which degradation products of TBP are produced. Within the AP Process, radiolysis of TBP predominately occurs in the organic phase due to the low solubility of TBP within the aqueous solution. Furthermore, within the organic phase, the predominant mechanism by which radiolysis occurs is attributed to the presence of plutonium. Thus, the mechanism of concern is alpha-induced radiolysis. Therefore, essentially all of the decay energy is deposited in the solution. Radiolysis rates generally depend on a large number of factors, such as radiation type (alpha, beta, or gamma radiation), dose rate, the concentrations of water, nitric acid and plutonium, the phase in which radiolysis occurs (aqueous or organic), the isotopic composition of plutonium, the presence or absence of air, the concentrations of radiolysis products, etc. Bombardment of solutions of TBP by alpha ionizing radiation generates fragments (radicals and ions) of water and chemicals in solutions. Radiolysis of a TBP/n-dodecane solution in the presence of nitric acid could produce butanol and butyl nitrate, along with other organic nitrates (RONO<sub>2</sub>), organic nitro compounds (RNO<sub>2</sub>), and organic nitrites (RONO). These are formed by the capture of hydrocarbon radicals (C<sub>n</sub>H<sub>2n+1</sub>, n = 1 - 4) by nitrogen dioxide. Analysis has

shown, in fact, that the rate of radiolysis-induced TBP degradation is approximately equal to that of the chemical degradation at 30°C under conditions present in the AP Process.

#### 8.5.1.5.3 Reaction Kinetics

The reactions governing the chemical degradation of TBP are presented in Figure 8.5-2. In order to understand the dynamics of the system, the heat generation rate, and the quantity of degradation products in the system at a given time, the rate coefficients governing each step in the degradation process must be determined.

Kinetic studies have shown that TBP degrades much faster in aqueous solutions than it does in organic solutions. However, in mixed aqueous-organic systems, the concentration of TBP in the aqueous system is so low compared to that in the organic phase that the effect of aqueous phase hydrolysis is expected to be negligible (the solubility of TBP is 0.3g/L of nitric acid and the volume ratio of organic to aqueous is 1:5). Therefore, the concern is with the degradation of organic in the organic phase.

There have been numerous investigations of the reaction rate of TBP in the organic phase. Experimental results have concluded that the hydrolysis of TBP was the rate-limiting step in the overall TBP degradation process. Furthermore, the hydrolysis reaction was determined to be first order in TBP and zeroth order in nitric acid.

An Arrhenius fit to the rate data has been obtained:

$$k_{HNO_3, TBP} = 4.3 * 10^{10} * \exp\left(-\frac{112}{RT}\right) \quad (8.5-6)$$

where  $k_{HNO_3, TBP}$  is the rate constant for the hydrolysis of TBP. The units for the activation energy are kJ/g-mol and temperature (T) is in Kelvin, and the gas constant (R) is equal to  $8.314 * 10^{-3}$  J/(g-mol K).

As indicated in Figure 8.5-2, TBP hydrolysis yields DBP. DBP may also undergo hydrolysis, which will result in the formation of MBP. MBP also undergoes hydrolysis and produces the same byproducts. It has been found that the first order rate constants for the hydrolysis reaction decrease in the order TBP>DBP>MBP. Thus, all hydrolysis may be conservatively given by the TBP hydrolysis rate for the purpose of quantifying reaction energetics.

#### 8.5.1.5.4 Reaction Energetics

Energetic reactions may involve TBP, nitric acid, plutonium nitrate/TBP adduct, and TBP degradation products due to both chemical reactions (nitration/oxidation/hydrolysis) and radiolysis (the exclusion of cyclic chain hydrocarbons eliminates the diluent as a contributor to the reaction energetics). However, it is assumed in the following discussions of reaction energies that the reactions of nitrate and TBP and associated by-products adequately describe the behavior of the TBP-nitrate systems. It is further assumed that diluent and reactive products of diluent

nitration are absent. From thermodynamic data, the total heat generated by the complete oxidation of TBP to carbon dioxide, phosphoric acid, and water by nitric acid has been calculated to be approximately 1689 kcal/mole. However, only approximately 20% of the energy content can be liberated due to the limited quantity of oxidizer present within the organic phase. The energetics are further reduced in an open system because the oxidation does not go to completion. Intermediate products such as CO, NO, and butyric acid remain and a portion of the oxidizer is evaporated from the system. Differential scanning calorimetry measurements indicate a reaction energy of approximately 67 kcal/mol in comparison to the theoretical value of 368 kcal/mole in the case of a 1:3 TBP to HNO<sub>3</sub> ratio. Explanation for this diminished energy release is attributed to both the evaporation of the oxidizer and some of the TBP degradation products. Thus, the experimentally measured energetic content of red oil is much smaller than typical explosive nitrated aromatic compounds such as TNT (4564 J/g) because of both the poor oxidant to fuel ratio in the TBP adduct and the evaporation of the oxidizer and by-products of degradation. Nevertheless, the energy available via TBP decomposition is substantial. Consequently, it is important to understand the means by which these reactions are limited to ensure that the energy generated via these reactions does not exceed the rate at which energy is removed from the system.

#### **8.5.1.5.5 AP Process Operating Conditions**

The reaction mechanisms for the degradation of TBP due to both chemical attack and radiolysis yield sufficiently energetic reactions that may proceed at appreciable rates under certain conditions such that over-pressurization and/or explosive conditions could arise. Ultimately, a runaway condition could occur if the rate of energy generation exceeds the rate at which heat is removed from the system. Therefore, mechanisms that ensure that the heat transfer and mass transfer of the reactants are adequate to control the system must be addressed.

Design bases to preclude a runaway condition must be viewed in aggregate. Principal SSCs and corresponding design bases synergistically provide reasonable assurance that runaway reactions will not occur (i.e., the combination of the control of the energy generation and heat transfer ensures that a runaway reaction is precluded).

Once a quantity of TBP and nitrate is heated to the point that it begins to react at an appreciable rate, subsequent reactions are determined by the heat removal processes available, and include:

- evaporation of water and other materials;
- heat transfer by conduction or convection to an aqueous phase;
- heat transfer to the vessel walls; and
- convective cooling by the gas in the head space.

In an unstirred closed vessel, geometric aspects influence the available heat transfer mechanisms. Chemical heating may occur in an organic phase overlying an aqueous phase. The floating organic phase is in the form of a disc, with its radius potentially much greater than its thickness in a cylindrical tank or vessel. Because organic solutions are generally poor conductors of heat, only a small region of the organic phase can be affected by cooling the vessel walls, and geometry inhibits establishment of large-scale convection processes with the organic phase. With the top of the aqueous phase being heated (producing a less dense top layer), there are no

gravitational forces producing convection in this phase. Downward heat transfer between the phases, therefore, involves conduction, rather than convection, and heat removal is consequently lower. This description represents the limiting system from the perspective of selecting a minimum initiation temperature for a runaway reaction.

DCS has selected a design basis temperature of 135°C to limit the heat generation rate. This design basis temperature is based on the experimentally determined minimum initiation temperature for a *closed* system and is derived from isothermal experimental conditions. Furthermore, selection of this design basis temperature ensures that the selected diluent (discussed below) will not undergo degradation and lower the minimum initiation temperature of a runaway reaction.

Based on experimental evidence, the exclusion of cyclic chain hydrocarbons in diluents indicates that temperatures far in excess of 135°C are necessary to initiate runaway reactions in *open* systems containing nitric acid. Experimental evidence also suggests that diluents containing a large fraction of cyclic hydrocarbons (i.e., ~20—30% naphthenes) undergo significant nitration at temperatures lower than corresponding systems composed of both TBP and diluent. Therefore, the nature of the diluent is relevant in establishing the temperature at which systems composed of TBP/diluent begin to “run -away.” The use of C<sub>10</sub>-C<sub>13</sub> branched chain hydrocarbons (aliphatic diluent HPT) in the AP process optimizes both the plutonium decontamination factor and the nitration resistance to ensure an adequate safety margin associated with the operation of the process. Consequently, DCS has identified the properties of the diluent as a principal SSC. The design basis for the diluent is to utilize a diluent containing no cyclic chain hydrocarbons.

DCS has also identified venting of vessels/equipment that may potentially contain TBP and its associated by-products as a principal SSC to provide additional heat transfer capability and to provide adequate safety margin. Venting provides the following benefits:

- limits pressurization of the system
- permits evaporation of dissolved water and/or nitric acid from the organic phase in an open system, which allows for additional heat transfer capability and, in the case of nitric acid, reduces the available energy by limiting reactants (this mode of heat transfer is much more efficient than the heat transfer provided by a closed system; experimental evidence suggests that this can dominate the energy balance at lower temperatures, causing a net cooling and slowing the chemical reaction);
- maintains a constant temperature in a boiling system (in an evaporator, for example, in which the entire contents are heated, the resultant turbulent mixing should keep the organic and aqueous phases at the same temperature, so that the overall temperature is controlled by the boiling aqueous phase);
- permits evaporation of a fraction of the degradation products (butanol and butyl nitrate) from the system thereby reducing the energy content of the system; and
- allows escape of NO<sub>x</sub>, the decomposition product of alkyl nitrates reacting to alcohol. NO<sub>x</sub>, in equilibrium with HNO<sub>2</sub>, may also play the role of catalyst for this decomposition reaction.

Also, historical evidence suggests that there is no violent reaction in a system with appreciable venting. Minimum vent sizes will be determined during final design.

The use of venting implies control of the bulk quantity of organics added to a given vessel. DCS has implemented the following features to preclude the transfer of bulk quantities of organic to heated equipment:

- A diluent washing pulsed column for washing the extracted plutonium aqueous stream
- A diluent washing pulsed column for washing the extraction process unloaded feeding solution ("raffinates stream")
- A diluent washing mixer-settler for washing the extracted uranium aqueous stream
- A diluent washing mixer-settler for washing the aqueous phase containing TBP degradation products from solvent recovery.

DCS is currently evaluating the principal SSCs that will be required to prevent bulk quantities of organic from entering process equipment that could exceed the associated minimum vent-size-to-organic-mass ratio. In the event that a quantity of organic material, sufficient to exceed the design basis vent size to organic mass ratio for a given vent dimension, could occupy a vessel/tank, controls to preclude the quantity of organic from being placed into the corresponding vessel will be identified in the ISA.

In addition, because gases are released during the chemical reactions, foaming may be possible. Foaming in the organic phase occurs as self-heating accelerates due to the gases generated. Significant amounts of foam could limit the effectiveness of the vent. In addition, foam can be thermally isolated from the rest of the system because of its insulating qualities. A foaming mass that is undergoing an exothermic reaction may therefore attain a higher temperature than a liquid in contact with a heat sink, such as water. When a cyclic diluent was utilized in past red oil incidents, foaming is believed to have occurred prior to a runaway condition. Again, the selection of a diluent containing no cyclic hydrocarbons and limitations on the temperature are implemented as principal SSCs to limit foaming and provide reasonable assurance that the vents remain effective.

#### **8.5.1.5.6 Impact of Tomsk-7 Event**

On April 6, 1993, at the Tomsk-7 nuclear fuel processing facility located in Siberia, Russia, there purportedly were two sequential explosions that caused physical damage to the facility and contaminated the facility and the surrounding area. The explosions appear to be due to the "red oil" phenomenon associated with nitric acid, TBP, and the hydrocarbon diluent used by the Russians, and was initiated by actions that constituted violations to operating procedures and operating conditions unlikely to occur at the MFFF. Inadequate venting was also a likely contributor in the explosion.

The Tomsk-7 event identified a new mechanism to the TBP degradation/red oil formation phenomenon. This arose from the apparent initiation of an energetic runaway reaction in the vicinity of 90°C, far below the previously observed minimum temperature for a runaway TBP hydrolysis-limited reaction. Several investigators postulated that the accumulation of two degradation products, butanol and butyl nitrate, may have been responsible for the lower



initiation temperature. Experimental results have verified that these two degradation products of TBP can, in the presence of concentrated nitric acid, release significant energy at temperatures far less than 135°C. Significant buildup of degraded organics is not expected at the MFFF (i.e., solvent is routinely used and regenerated as part of normal operations, and most degraded organics are destroyed during normal operation). Nonetheless, such a buildup is conservatively postulated.

Butanol, a TBP degradation product, is rapidly and completely converted to butyl nitrate at temperatures of 110°C to 120°C, and is oxidized further to butyric acid, propionic acid, and acetic acid when contacted with moderate to strong (6M to 15.8M) nitric acid. Butyl nitrate oxidation begins as solutions with 10M to 15.8M nitric acid are heated to between 52°C and 85°C, and these reactions are strongly exothermic. The heat of reaction for butanol oxidation has been determined to be -466 cal/g (-1948 J/g) of butanol based on a 1:1 butanol to nitric acid ratio. The negative heat of reaction favors the formation of butyl nitrate in this reaction equilibrium. Additional experimental results indicate that even at a fairly low concentration of nitric acid (0.8M), butanol is converted to butyl nitrate at about 100°C.

Thus, in order to determine whether the accumulation of TBP degradation products butanol and butyl nitrate can provide the initial energy release via oxidation to raise the organic phase temperature to above 135°C, a determination of the quantity of each species in solution must be obtained (unlike the pre-Tomsk-7 operating assumption that, in the formulation of a model to describe TBP degradation at elevated temperatures, the oxidation reactions proceeded much more rapidly than the hydrolysis reaction and consequently degradation products did not build up).

To determine the quantity of degraded organics necessary to raise the temperature of the bulk organic to 135°C, the minimum initiation temperature for a runaway reaction, the total quantity of organic necessary support a runaway reaction in an open system is calculated utilizing the vent-to-organic-mass ratio described above. A heat balance is then utilized to calculate the quantity degraded organic necessary to elevate the bulk organic temperature to 135°C.

Preliminary analyses have indicated that the organic mass in a vessel or tank must be limited to on the order of 30 kg of organic material. Based on conditions that could be encountered during unlikely extended shutdowns, the mass of degraded organics necessary to elevate the bulk organic temperature to the 135°C is a few kilograms. The total degraded organic/TBP mass is given by the production rates from both radiolysis and hydrolysis minus the amount of degraded organic lost to the system from evaporation and oxidation via the nitric acid. These preliminary analyses indicate the degraded mass is reached in on the order of years. Consequently, the principal SSCs are established to provide reasonable assurance that significant quantities of butanol and/or butyl nitrate do not build up in the process. The design basis for these controls is limiting the residence time of organics in the presence of oxidizers such as nitric acid (i.e., in process vessels containing oxidizing agents and potentially exposed to high temperatures), and radiation fields, to limit the quantity of degraded organics that may buildup in the system either through hydrolysis and/or radiolysis.

#### 8.5.1.6 Pyrophoricity of Uranium and Plutonium

Both plutonium and uranium metals are pyrophoric and readily ignitable when existing in a finely divided form. When these metals are present in large or massive forms they do not present a significant fire risk. When these metals exist in the dioxide form (e.g.,  $\text{PuO}_2$  and  $\text{UO}_2$ ) they are relatively stable and not considered pyrophoric. The MFFF only handles these materials in the dioxide form.

While the fire risk associated with the dioxide forms of U and Pu is low, hazards associated with handling of these materials do exist. Uranium dioxide can undergo further oxidation to higher oxides resulting in spontaneous heating. Sub-stoichiometric plutonium oxides formed by incomplete or partial oxidation of plutonium metal can be pyrophoric. These hazards are described below.

##### 8.5.1.6.1 $\text{UO}_2$

At elevated temperatures, finely divided  $\text{UO}_2$  can undergo further oxidation to higher uranium oxides, specifically  $\text{U}_3\text{O}_8$ . This reaction results in spontaneous heating of the oxide and is typically referred to as "burnback." In the past, this phenomenon has been associated with fires at fuel fabrication facilities handling  $\text{UO}_2$ . In these events, the oxidizing uranium powder was believed to be heated by some mechanical failure (i.e., friction) which initiated the burnback reaction and released heat. Combustible materials such as transfer hoses and boots then provided the fuel to support a fire.

In addressing this hazard, the SA has identified  $\text{UO}_2$  spontaneous heating as a cause for fire in a glovebox. Also, the heat generated by the burnback phenomenon has been considered in the thermal analysis of facility gloveboxes as described in Section 5.5.2.1.6.9. The specific power of  $\text{UO}_2$  oxidation is taken into account using the following design basis values:

- If  $T < 74^\circ\text{C}$  ( $165.2^\circ\text{F}$ ) then  $P_{\text{ox}} = 0 \text{ W/kg}$  ( $0 \text{ W/lb}$ ) of  $\text{UO}_2$ ,
- If  $74^\circ\text{C}$  ( $165.2^\circ\text{F}$ )  $< T < 340^\circ\text{C}$  ( $644^\circ\text{F}$ ) then  $P_{\text{ox}} = 1.1 \text{ W/kg}$  ( $0.499 \text{ W/lb}$ ) of  $\text{UO}_2$ ,
- If  $T > 340^\circ\text{C}$  ( $644^\circ\text{F}$ ) then  $P_{\text{ox}} = 4.63 \text{ W/kg}$  ( $2.1 \text{ W/lb}$ ) of  $\text{UO}_2$

where  $T$  is the powder temperature.

Although not identified as principal SSCs to address this specific hazard, the following features of the  $\text{UO}_2$  storage/handling processes provide additional protection:

- $\text{UO}_2$  delivered to the MFFF site and stored in steel drums, double bagged under a  $\text{N}_2$  atmosphere
- $\text{UO}_2$  maintained in a  $\text{N}_2$  atmosphere throughout the process
- Fire detection and suppression systems provided for gloveboxes ( $\text{CO}_2$  injection) and process rooms (clean agent)
- Use of noncombustible or nonflammable materials for process equipment construction and furnishing

- Control of combustible materials.

These additional protection features incorporate selected recommendations of NRC Information Notice 92-14, *Uranium Oxide Fires at Fuel Cycle Facilities*. Consideration of recommended administrative controls (operator training, process unit operator attendance, etc.) will be addressed in facility procedures.

#### 8.5.1.6.2 PuO<sub>2</sub>

Although PuO<sub>2</sub> is unreactive in air, sub-stoichiometric compounds of plutonium can be formed as a result of partial oxidation of plutonium metal. These compounds can be pyrophoric and when exposed to an oxidizing atmosphere could rapidly form PuO<sub>2</sub> while releasing heat. To control this hazard the MFFF will ensure that a stable PuO<sub>2</sub> form is introduced to the MFFF.

Plutonium feed material is received at the MFFF from the Pit Disassembly and Conversion Facility (PDCF). A small quantity of feed material (alternate feed stock) will initially be supplied from alternate sources until the PDCF is operational. To ensure stability of the MFFF Pu feed material, both of these sources will supply PuO<sub>2</sub> satisfying the requirements of DOE-STD-3013-2000, *Stabilization, Packaging, and Storage of Plutonium-Bearing Materials*. Specifically, the requirement that oxide material be placed in a continuously oxidizing atmosphere at a material temperature of at least 950° C for a minimum of two hours ensures a stable product. Not only does this requirement eliminate sub-stoichiometric plutonium oxides and finely divided metal, it also achieves the following additional stabilization objectives:

- Elimination of organic materials
- Reduction of water content to less than 0.5 wt% and reduction of quantities of species that may produce water
- Minimization of potential for water readsorption above the 0.5% threshold
- Stabilization of any other potential gas-producing constituents

DOE-STD-3013-2000 accepts two methods of verification that materials have been adequately stabilized. These methods are 1) testing of every container loading or 2) use of a "qualified process" for stabilization and packaging that would reduce the requirements for materials testing. Details of the method to verify the receipt of stabilized material will be addressed in the ISA.

The formation of sub-stoichiometric oxides is associated with the conversion of plutonium metal to oxide. The conversion process step associated with MFFF aqueous polishing converts plutonium oxalate to plutonium dioxide. The formation of sub-stoichiometric oxides during this conversion process is not a concern as reduction of the Pu (IV) oxalate does not occur.

It should also be noted that the thermal power generated by the decay of plutonium has been taken into account in the design. The design basis values are as follows:

- Unpolished Pu: 2.9 W/kg of unpolished PuO<sub>2</sub> powder
- Polished Pu: 2.2 W/kg of polished PuO<sub>2</sub> powder

See section 5.5.2.1.6.9 for additional details regarding the effects of decay heat.

#### 8.5.1.7 Plutonium (VI) Oxalate

Plutonium oxalate is produced in the VI valence state in the plutonium dissolution unit and dechlorination unit, where it is reduced utilizing  $H_2O_2$  to Pu (IV) prior to entering the purification unit. In addition, Pu (VI) is produced within the oxalic mother liquor recovery unit. This material is then re-introduced into the purification unit. Within the purification unit, Pu(VI) is reduced by the hydroxylamine and oxidized to Pu(IV). Within the oxalic precipitation and oxidation unit, the plutonium oxalate is precipitated via the addition of oxalic acid. In the event of a failure to oxidize Pu (IV) within the purification unit following HAN reduction and subsequent oxidation, Pu (VI) oxalate could be produced within the oxalic precipitation and oxidation unit. The Pu (VI) oxalate could then be introduced into the calcining furnace, which would create a hazard as discussed below.

Experimental evidence performed using differential thermal analysis (DTA) has evaluated the activation energy and order of the reaction for the thermal decomposition of  $PuO_2 \cdot C_2O_4 \cdot 3H_2O$  in air. The DTA curve for Pu (VI) oxalate shows a broad endothermic peak (due to dehydration) with a maximum at  $142^\circ C$  and a sharp exothermic peak (oxidation of the oxalate) with a maximum at  $219^\circ C$ . The dehydration enthalpy was determined to be 13 kcal/mole and the exothermic reaction was found to be -25 kcal/mole. Although not particularly exothermic, the decomposition is rapid and can be explosive. (Plutonium (VI) is likely to be reduced to Pu (III) as an intermediate oxidation state in this reaction, but, as with Pu(IV) oxalate, the final product will be  $PuO_2$ .) Therefore, DCS has implemented a preventative safety strategy to satisfy the performance requirements of 10 CFR §70.61.

The design basis to control this hazard is to preclude the introduction of Pu(VI) oxalate into heated equipment where temperatures in excess of  $219^\circ C$  are credible. In addition, controls will be in place to ensure that temperatures do not exceed  $219^\circ C$  where plutonium (VI) oxalate may be present (e.g., in the oxalic mother liquor recovery unit and in the oxalic precipitation and oxidation unit). The specific temperature setpoints will be determined during final design.

#### 8.5.1.8 Hydrazoic Acid

Hydrazoic acid, also known as hydrogen azide ( $HN_3$ ), is formed when hydrazine ( $N_2H_4$  or  $N_2H_5^+$ ) is oxidized by nitrous acid (equation 8.5-7). Further oxidation leads to the formation of nitrous oxide and nitrogen gases (Equation 8.5-8).



The competitive nature of the hydrazoic acid formation reaction (equation 8.5-7) and its scavenging reaction (equation 8.5-8) initially establishes preferable generation of hydrazoic acid due to the faster reaction kinetics associated with nitrous acid and hydrazine (equation 8.5-7).

However, due to the scavenging properties of hydrazoic acid, an equilibrium concentration of hydrazoic acid will be reached within a solution containing hydrazine and nitrous acid. The maximum equilibrium concentration of hydrazoic acid is set by the hydrazine concentration, whereas the equilibrium concentration in the process is based on the quantity of nitrous acid available for reaction.

Hydrazoic acid is a colorless liquid that is very soluble in water. It is a relatively weak acid with the approximate strength of acetic acid ( $pK_a = 4.77$ ). Hydrazoic acid is an unstable compound, especially in the pure chemical form when heated or shocked. Its relatively low boiling point ( $T = 35.7^\circ\text{C}$  under atmospheric pressure) makes it volatile at room temperature. The activation energy has been determined to be 147 kJ/mole. In the presence of metal ions, hydrazoic acid can transform into a metal azide. More details of these azide reactions are covered in Section 8.5.1.9.

Energetic decomposition of hydrazoic acid can occur both in an aqueous liquid phase, when the threshold concentration of 4.7 mol/L is reached (i.e., the lower explosive concentration limit, LECL for the pure chemical form) and also in a gaseous phase as given by equation 8.5-9. The threshold partial pressure moving hydrazoic acid into an explosive regime has been experimentally determined to be 25 to 68 Torr (0.09 atm) and theoretically established to be 19 Torr (0.025 atm).



For the AP processes, the specific hydrazoic acid risk in the gaseous phase is related to its phase transfer from the liquid phase (aqueous or organic) to the gaseous phase, per equations 8.5-10 and 8.5-11.



The partial pressure of hydrazoic acid in the gaseous phase,  $P_{HN_3}$ , is related to hydrazoic acid concentration in the aqueous phase or to the hydrazoic acid—TBP complex ( $TBP \cdot HN_3$ ) concentration in the organic phase, by the Henry coefficient (H):

$$H(\text{atm} \cdot \text{L/mol}) = P_{HN_3} / [HN_3] \quad (8.5-12)$$

Utilizing Henry's Law and the more conservative theoretical partial pressure, the limiting hydrazoic acid explosive concentration is determined for both the aqueous and organic phase as follows:

- **For hydrazoic acid in aqueous phase that could subsequently be transferred to the gaseous phase and result in an explosion risk:**

Explosive decomposition of hydrazoic acid could occur in the aqueous phase when the threshold concentration of 4.7 mol/L is reached. The kinetic study of hydrazoic acid desorption from an aqueous phase to the gaseous phase has shown that the Henry coefficient for  $\text{HN}_3$  may be expressed by the following formula for temperatures varying from 25 to 60°C:

$$H(\text{atm} \cdot \text{L/mol}) = C \exp(-E_a/RT) = 75,475 \exp(-4,001.9/T) \quad (8.5-13)$$

where T is the temperature in Kelvin. This formula accounts for a desorption activation energy of 8 kcal/mol (33.4 kJ/mol).

Utilizing equations 8.5-12 and 8.5-13 and the theoretically determined partial pressure threshold of 19 Torr (0.09 atm) for the gaseous phase, the minimum hydrazoic acid concentration in 0.1 to 1 M nitric acid for solutions to reach the explosive concentration in the gaseous phase has been determined to be 0.055 mol/L at 60 °C. This concentration and its associated temperature can be used to preclude the explosion risk in the gaseous phase from the aqueous phase of solutions found in various AP pieces of equipment that may contain hydrazine.

- **For hydrazoic acid in organic phase, that could subsequently be transferred to the gaseous phase and result in an explosion risk:**

Hydrazoic acid is soluble in the organic phase composed of TBP 30%, HTP 70%. The kinetic study of hydrazoic acid desorption from an organic phase to a gaseous phase has shown that the desorption activation energy is 16 kcal/mol (66.8 kJ/mol). The theoretically determined partial pressure of 19 Torr corresponds to a concentration of 1.4 mol/L at 25°C in the organic phase. The Henry coefficient (H) as a function of temperature can thus be expressed by the following formula:

$$H(\text{atm} \cdot \text{L/mol}) = C \exp(-E_a/RT) = 9.5 \times 10^9 \exp(-8038/T) \quad (8.5-14)$$

where T is the temperature in Kelvin. Accounting for a maximum process temperature of 60°C, the minimum hydrazoic acid concentration to reach the explosive concentration in the gaseous phase has been determined to be 0.08 mol/L. This concentration and its associated temperature can be used to preclude the explosion risk in the gaseous phase from the organic phase of solutions found in various AP pieces of equipment that may contain hydrazine.

When utilizing the theoretical value as the limiting concentration for the hydrazoic acid, the yield of hydrazoic acid derived from the reaction between nitrous acid and hydrazine becomes an

important parameter that limits the quantity of hydrazoic acid in the system. The yield of hydrazoic acid from the reaction between hydrazine and nitrous acid is determined predominately by both the relative reaction rates of the nitrous acid reaction with hydrazine and hydrazoic acid, and the concentration of hydrazine present in the system, which is added to the Purification Cycle at 0.14 mol/L. A yield of 39.3% or less is necessary (0.055/0.14) to ensure limiting conditions are not present in the AP processes.

Thus, the design basis to control the risk related to hydrazoic acid explosions is as follows: ensure the hydrazoic acid yield is 39.3% or lower, ensure a maximum hydrazine concentration of 0.14 moles per liter is used, and ensure a maximum temperature of 60°C where these chemicals are used in the AP process. DCS will perform analysis in the ISA to establish a bounding hydrazoic acid yield and implement any necessary controls to ensure that the hydrazoic yield is below 39.3%, which ensures that the critical concentration of 0.055 mol/L of hydrazoic acid is not exceeded.

It should be noted that the corresponding limitations on the hydrazoic acid yield assume adiabatic conditions. DCS is currently investigating more realistic heat transfer that may be utilized in the ISA to justify the use of a larger threshold partial pressure (i.e., greater than 19 Torr, which is the theoretically calculated partial pressure of hydrazoic acid).

In addition to the previously identified design basis, sampling controls are also implemented to ensure that the process of transforming the hydrazoic acid to sodium azide within the Solvent Recovery Unit is effective to ensure that hydrazoic acid does not accumulate in the process to a limiting concentration due to the continuous injection of hydrazine into the Purification Cycle. This sampling control also ensures that azides are not formed within the extraction and diluent washing pulse columns of the Purification Cycle (i.e., PULS2000 and PULS2200) due to the potential presence of metal impurities within these columns.

An additional case involves the evaporation of hydrazoic acid in solution at low temperatures (e.g., approximately 20°C) and subsequent condensation of the hydrazoic acid in the ventilation system. In this case, it is theoretically possible to reach a limiting for the hydrazoic acid concentration to reach the explosive threshold in the condensing aqueous solution of 0.055 mol/L (limiting value based on theoretical threshold partial pressure). At higher temperatures (i.e., greater than approximately 20°C), the gaseous phase contains sufficient water vapor to ensure that if any vapor is condensed, limiting concentrations of hydrazoic acid cannot be obtained. The partial pressure of hydrazoic acid will be dramatically reduced, however due to the dilution in the ventilation system; further unrealistically low temperatures would need to be present in the ventilation system in order for hydrazoic acid condensation to occur. Consequently, DCS will perform additional analyses during the ISA to determine if any additional controls are necessary to preclude the condensation of hydrazoic acid inside the ventilation system.

#### **8.5.1.9 Metal Azides**

The azide anion,  $N_3$  forms adducts with metallic cations. Metal azides, formed in basic media from metallic cations and hydrazoic acid interaction, are slightly soluble to non-soluble (e.g., Ag or Zr) in aqueous media. Characteristics of the bond between the anion and the cation, which

form the azide salt, can cause these compounds to become unstable under specific conditions. The most unstable azide salts are the heavy metallic salts that form covalent bonds with  $\text{N}_3^-$ .

Most azides in pure chemical form decompose when heated. Azide salts are thus not stable when placed in dry conditions at temperatures far above  $135^\circ\text{C}$ . With the exception of the calcining furnace, this is the limiting temperature within the AP Process.

With the exception of hydrazoic acid, the AP process precludes any significant production of azides. This is accomplished by the removal of a significant fraction of the impurities in the plutonium feedstock introduced into the front end of the Purification Cycle (i.e., into the extraction pulse column, PULS2000) and by the absence of hydrazoic acid from the columns and tanks that may contain these impurities. The absence of hydrazoic acid from the front end of the Purification Cycle is assured due to sampling controls whose function is to detect hydrazoic acid prior to reintroducing solutions into the front end of the Purification Cycle (e.g., TK100Q or PULS2000).

In the plutonium stripping pulsed column (PULS3000) and equipment downstream of this column, hydrazoic acid is present due to the introduction of hydrazine into the plutonium barrier mixer-settler (MIXS4000) which feeds PULS3000 and subsequent downstream equipment. In the event that metal azides are formed within this Purification Cycle equipment, the azides will reside in the aqueous phase which is introduced into the oxidation column (CLMN6000) within the Purification Cycle prior to transfer to a downstream unit. Within the oxidation column, the azides will be destroyed due to the presence of nitrous acid which reacts with the azide to produce a nitrogen gas.

Finally, prior to being introduced into the calcining furnace, the solution is sampled to further ensure that azides are not introduced into the furnace whose temperature may exceed  $140^\circ\text{C}$ . This sampling measurement which ensures that azides are not present is identified as a principal SSC. In addition, the Process Safety Control Subsystem is also identified as a principal SSC to ensure that equipment potentially containing azides are not exposed or raised to temperatures that could exceed  $135^\circ\text{C}$ .

As discussed previously, azides in a dry environment are also unstable with respect to shocks due to the weak intermolecular force holding the azide together. Consequently, to ensure that conditions do not exist to create this potential hazard, administrative controls have been identified as the principal SSC to ensure that tanks potentially containing azides are not left dry. Previously identified process controls and the sampling controls to limit the presence of hydrazoic acid in process vessels are also used to preclude this potential explosion event.

Additional details on specific azides that could potentially be formed within the AP Process are provided below.

#### **Plutonium and Uranium Azides**

The azide anion can form soluble weakly bonded azido complexes with uranium and plutonium at molar ratios of  $\text{HN}_3/\text{Pu}$  and  $\text{HN}_3/\text{U}$  less than one. Considering the bounding hydrazoic acid ( $\text{HN}_3$ ) concentration developed in the previous section is  $0.055 \text{ mol/L}$ , the plutonium/uranium



concentration in process vessels in which this condition could exist must be very low. Furthermore, the formation of solid uranium or plutonium azides in alkaline solutions may be safely excluded because hydroxide or carbonate complexes are preferentially formed, and therefore the production of uranium and plutonium azides is expected to be much less than 0.055 mol/L.

### Silver Azide ( $\text{AgN}_3$ )

Contact of hydrazoic acid with silver nitrate in the process can form silver azide salts in accordance with the following:



The initial silver concentration upstream of the Purification Cycle is approximately 0.011 mol/L. TBP liquid/liquid extraction operates with a decontamination factor for silver of approximately  $2 \times 10^5$ . No silver has ever been detected downstream of the extraction step in operating installations at the Cogema UP3 facility, based on mass spectrometry detection threshold for silver of  $9.3 \times 10^{-9}$  mol/L. The silver nitrate concentration reaching the "Pu stripping" (PULS3000) and "Pu barrier" (MIXS4000) purification steps can therefore be assumed to be less than  $5.5 \times 10^{-8}$  mol/L ( $0.011/2 \times 10^5$ ) under anticipated conditions.

The credited principal SSC required to meet the performance requirements of 10 CFR §70.61 is the Process Safety Control Subsystem, which ensures the temperatures in process vessels that may potentially contain hydrazoic acid are maintained below 140°C, which is below the thermal decomposition temperature of silver azide.

As described above, the presence of silver azide is limited to equipment within the Purification Cycle downstream of the plutonium stripping pulse column (PULS3000). This limitation on the location of the silver azide is attributed to a process that destroys azides and hydrazoic acid that may have formed in the Purification Cycle and Solvent Recovery unit. As previously stated, sampling controls which have been identified as a principal SSC confirm the effectiveness of the destruction of both azides and hydrazoic acid prior to transfers of solutions for processing by downstream units.

### Sodium Azide ( $\text{NaN}_3$ )

Sodium azide results from the reaction between sodium cations and azide anions as follows:



In the Solvent Recovery unit, sodium (in the form of sodium carbonate and sodium hydroxide) is added to the solvent washing mixer-settler (MIXS1000). This sodium reacts with the hydrazoic

acid formed in the Purification Cycle producing sodium azide. The maximum concentration of azide in the system is 0.058 M. Thus, as in nitric acid media, the solubility of sodium azide is approximately 6.3 M at 25°C, the minimum concentration of sodium needed for sodium azide to precipitate would be 684 M ( $[Na^+][N_3^-] = 6.3^2$ ), i.e., 342 M of  $Na_2CO_3$ . Such value cannot be reached as the solubility of  $Na_2CO_3$  in water at 25°C is equal to 4 M, so that the concentration of sodium azide formed as a result of the neutralization reactions is limited within safety requirements. Consequently, no additional safety controls are required.

To limit the propagation of the sodium azide within the AP process, DCS will incorporate a process to destroy the sodium azide. This process relies on the addition of sodium nitrite followed by acidification.

As previously discussed, the sampling principal SSC will ensure the effectiveness of the process to destroy sodium azide. This destruction is necessary prior to the introduction of the waste stream containing the sodium azide into acidified solutions due to the possible liberation of hydrazoic acid from the solution which is possible if the normality of the solution is in excess of 0.426 M nitric acid.

#### **8.5.1.10 Nitrogen Dioxide/Dinitrogen Tetroxide**

Dinitrogen tetroxide is stored in cylinders in the Reagents Processing Building in liquefied form. Instrument air is injected into the cylinder to transfer the liquid into an electric boiler, also located in the Reagents Processing Building, where it is vaporized to gaseous nitrogen dioxide and other  $NO_x$  gases prior to entry into the aqueous polishing area.

Under normal operations, the vaporized gases are reacted with the hydrazine, HAN, and hydrazoic acid that are present with plutonium nitrate in the oxidation column (CLMN6000) of the purification cycle of the Aqueous Polishing process. If these gases or the unreacted nitrogen dioxide/dinitrogen tetroxide gases are released from the stack the consequences to all potential receptors are acceptable (no offgas treatment is required).

However, if the process fails (e.g., the flow of plutonium nitrate with hydrazine, HAN, and hydrazoic acid is deterministically assumed to be abnormally terminated to the oxidation column) and/or the nitrogen dioxide/dinitrogen tetroxide supplied to the oxidation column flows at an abnormally high rate, then there is the potential for chemical consequences associated with the release of these gases that may have come into contact with licensed materials to be unacceptable to the site worker. As described in section 5.5.2.10, the flow of nitrogen dioxide/dinitrogen tetroxide is limited to the oxidation column such that chemical consequences to the site worker are acceptable. The design basis value is the TEEL-2 limit for nitrogen dioxide/dinitrogen tetroxide listed in Table 8-5. This is the value that will not be exceeded during normal and off-normal conditions. To exceed this value, preliminary calculations indicate a flow rate in excess of approximately 44 kg/hr is necessary. The normal flow rate is approximately 1.3 kg/hr. Calculations will be performed as part of detailed design (and summarized in the ISA) to determine the appropriate means to assure the TEEL-2 limit is not exceeded.

### **8.5.2 Design Bases During Normal Operations**

Chemical process and control system descriptions and their associated design bases are provided in Sections 11.3, 11.6, and 11.8.

### **8.5.3 Chemical Process Safety Design Features**

Principal SSCs related to chemical process safety are discussed in Section 5.5 and the design basis associated with these features are provided in Section 8.5.1. Specific setpoint ranges will be identified as part of detailed design and provided as part of the ISA Summary submitted with the license application for possession and use of SNM.

### **8.5.4 Principal SSCs**

Principal SSCs are discussed in Section 5.5.

### **8.5.5 Graded Approach to Safety**

The application of graded controls on principal SSCs and IROFS according to their safety function and significance is described in Section 15.1.

### **8.5.6 Management Measures**

Management measures are described in Chapter 15.

## **8.6 CHEMICAL PROCESS SAFETY INTERFACES**

Chemical safety related to storage, handling, and processing of licensed material (and hazardous chemicals produced from license material) is provided through integration of chemical safety analyses with the ISA (see Chapter 5). Controls established for chemical safety are consistent with those established for radiological safety and criticality safety, as are the associated management measures. Accordingly, the chemical safety program is conducted under the same elements of programmatic infrastructure described in Chapters 4, 12, and 14, and interfaces with the management measures discussed in Chapter 15.

### **8.6.1 Organizational Structure**

The Duke Cogema Stone & Webster (DCS) MFFF organization structure is described in Chapter 4, including designation of positions within the DCS organization responsible for principal SSCs. Principal SSCs are established for radiological, chemical, and criticality control in accordance with 10 CFR §70.61. Thus, the positions responsible for principal SSCs, as indicated in Chapter 4, also are responsible for chemical safety. Chapter 5 also indicates positions responsible for the conduct of the ISA. Since the ISA includes evaluation of chemical hazards, these positions also are responsible for the conduct of chemical safety analysis.

As indicated in Chapter 4, DCS will maintain continuity of control over principal SSCs during and following the transition from design and construction to operations. This control will also extend to chemical safety as an integrated component of the ISA process.

## **8.6.2 Human Factors**

Human factors engineering for personnel activities relied on for safety is discussed in Chapter 12. The MFFF is a highly automated facility based in large part on existing facilities. Criteria for human factors engineering are applied to the design of principal SSCs with associated personnel activities for operation or maintenance. These operations will include those associated with chemical processes, both inherently (i.e., the AP and MP processes are intrinsically chemical processes) and explicitly (i.e., the scope of human factors engineering is associated with control of principal SSCs whose function is protection against radiological, chemical, and criticality hazards).

## **8.6.3 Emergency Management**

An emergency plan is not expected to be required to be submitted for approval (see Chapter 14). However, the MFFF emergency management program will be integrated with the SRS and F-Area emergency preparedness programs, which include appropriate consideration of chemical-related accidents.

## **8.6.4 Quality Assurance**

The quality assurance program provides confidence that principal SSCs provide adequate protection against potential radiological, chemical, and criticality hazards. SSCs and personnel actions relied on for chemical safety are controlled under the same program as those established for radiological and criticality hazards. The DCS MOX Project Quality Assurance Plan (MPQAP) is described in Section 15.1.

## **8.6.5 Configuration Management**

The configuration management program will provide oversight and control of design bases and modifications (both temporary and permanent) to SSCs and management measures relied on for safety, including those associated with chemical safety. The MFFF configuration management program is described in Section 15.2.

## **8.6.6 Maintenance**

The MFFF maintenance program is described in Section 15.3. Surveillance, preventative and corrective maintenance, and post-maintenance testing are applied to principal SSCs as appropriate to help ensure their reliability and availability. Chemical safety SSCs are included as part of this maintenance program.

## **8.6.7 Training and Qualification**

Qualification of personnel and training to conduct IROFS activities are applicable to those functions that involve principal SSCs for protecting against radiological, chemical, and criticality hazards. Personnel responsible for performing activities involving chemical safety will be qualified and trained in accordance with the MFFF training program, as described in Section 15.4.

#### **8.6.8 Plant Procedures**

Activities associated with principal SSCs are conducted in accordance with appropriate procedures. In the operating MFFF, plant procedures govern operations, maintenance, emergency response, and administrative actions and ensure that principal SSCs are operated in a manner consistent with the ISA. Plant procedures associated with SSCs relied on for chemical safety will take into account chemical hazards, as well as radiological and criticality hazards, as appropriate for the activity. MFFF plant procedures are described in Section 15.5.

#### **8.6.9 Audits and Assessments**

Audits and assessments will be used to determine the effectiveness of management measures, including those associated with chemical safety. Audit and assessment attributes (including independence of auditors from personnel responsible for the chemical safety activities being audited, reports to management, and so forth) are consistent with those for other principal SSCs. The MFFF audits and assessments program is described in Section 15.6.

#### **8.6.10 Incident Investigations**

Incident investigation activities will identify corrective actions for and root causes of incidents that affect principal SSCs for chemical safety, as appropriate. As necessary, such investigations will identify actions to preclude recurrence of the incident. These incident investigations will be conducted in accordance with an incident investigation program used for all principal SSCs, described in Section 15.7.

#### **8.6.11 Records Management**

Chemical safety records are controlled in accordance with the configuration management system, the requirements of the MPQAP, and the records management program described in Section 15.8. Chemical safety records are processed and retained in the same manner as records associated with other principal SSCs and related programs.

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## Tables

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**Table 8-1a. Process Chemicals in the Reagent Processing Building (BRP)**

<b>CHEMICAL</b>			
<b>Name</b>	<b>Formula</b>	<b>CAS Number (Note 3)</b>	<b>STATE</b>
Diluent (C10-C13 Isoalkanes)	C10-C13 Isoalkanes	68551-17-7	Liquid
Hydrazine Monohydrate	N <sub>2</sub> H <sub>4</sub> .H <sub>2</sub> O	7803-57-8	Liquid
Hydrazine Nitrate (Note 1)	N <sub>2</sub> H <sub>4</sub> -HNO <sub>3</sub>	13464-97-6	Liquid
Hydrogen Peroxide	H <sub>2</sub> O <sub>2</sub>	7722-84-1	Liquid
Hydroxylamine Nitrate	NH <sub>2</sub> OH-HNO <sub>3</sub>	13465-08-2	Liquid
Nitric Acid	HNO <sub>3</sub>	7697-37-2	Liquid
Nitrogen Dioxide (Note 2)	NO <sub>2</sub>	10102-44-0	Gas
Nitrogen Tetroxide	N <sub>2</sub> O <sub>4</sub>	10544-72-6	Liquid/ Gas
Oxalic Acid	H <sub>2</sub> C <sub>2</sub> O <sub>4</sub>	144-62-7	Solid/ Liquid
Sodium Carbonate	Na <sub>2</sub> CO <sub>3</sub>	497-19-8	Solid/ Liquid
Sodium Hydroxide	NaOH	1310-73-2	Liquid
Tributyl Phosphate	(C <sub>4</sub> H <sub>9</sub> ) <sub>3</sub> PO <sub>4</sub>	126-73-8	Liquid

**Table 8-1a Notes:**

1. Hydrazine nitrate is made up in the BRP from hydrazine hydrate and nitric acid.
2. Nitrogen dioxide is the coexisting dimer of nitrogen tetroxide in gas form.
3. CAS Number refers to Chemical Abstract Services Registry Number.

**Table 8-1b. Process Chemicals in the Aqueous Polishing Building (BAP)**

<b>CHEMICAL</b>			
<b>Name</b>	<b>Formula</b>	<b>CAS Number</b>	<b>STATE</b>
Aluminum Nitrate	$\text{Al}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$	13473-90-0	Liquid
Chlorine (Note 1)	$\text{Cl}_2$	7782-50-5	Gas
Diluent (C10-C13 Isoalkanes)	C10-C13 Isoalkanes	68551-17-7	Liquid
Hydrazine Nitrate	$\text{N}_2\text{H}_4 \cdot \text{HNO}_3$	13464-97-6	Liquid
Hydrogen Peroxide	$\text{H}_2\text{O}_2$	7722-84-1	Liquid
Hydroxylamine Nitrate	$\text{NH}_2\text{OH} \cdot \text{HNO}_3$	13465-08-2	Liquid
Manganese Nitrate	$\text{Mn}(\text{NO}_3)_2$	10377-66-9	Solid/ Liquid
Nitric Acid	$\text{HNO}_3$	7697-37-2	Liquid
Nitric Oxide (Note 1)	$\text{NO}$	10102-43-9	Gas
Nitrogen Dioxide	$\text{NO}_2$	10102-44-0	Gas
Nitrogen Oxides (Note 1)	$\text{NO}_x$	N/A	Gas
Oxalic Acid	$\text{H}_2\text{C}_2\text{O}_4$	144-62-7	Solid/ Liquid
Plutonium Dioxide	$\text{PuO}_2$	N/A	Solid
Plutonium Oxalate (Note 2)	$\text{Pu}(\text{C}_2\text{O}_4)_2$	N/A	Solid/Liquid
Plutonium Nitrate (Note 2)	$\text{Pu}(\text{NO}_3)_3$ , $\text{Pu}(\text{NO}_3)_4$ , $\text{PuO}_2(\text{NO}_3)_2$	N/A	Liquid
Silver Nitrate	$\text{AgNO}_3$	7761-88-8	Solid/ Liquid
Sodium Carbonate	$\text{Na}_2\text{CO}_3$	497-19-8	Solid/ Liquid
Sodium Hydroxide	$\text{NaOH}$	1310-73-2	Liquid
Tributyl Phosphate	$(\text{C}_4\text{H}_9)_3\text{PO}_4$	126-73-8	Liquid
Uranium Dioxide	$\text{UO}_2$	1344-59-8	Solid
Uranyl Nitrate (Note 2)	$\text{UO}_2(\text{NO}_3)_2$	36478-76-9	Liquid
Zirconium Nitrate	$\text{Zr}(\text{NO}_3)_2 \cdot 5\text{H}_2\text{O}$	13746-89-9	Liquid

**Table 8-1b Notes:**

1. Chlorine and nitrogen oxides are by-products of AP processing.
2. Plutonium oxalate, plutonium nitrate, and uranyl nitrate are intermediate products of AP processing.

**Table 8-1c. Process Chemicals in the MOX Processing Building (BMP)**

<b>CHEMICAL</b>			
<b>Name</b>	<b>Formula</b>	<b>CAS Number</b>	<b>STATE</b>
Azodicarbonamide	$\text{H}_2\text{NCONNCONH}_2$	123-77-3	Solid
Isopropanol	$\text{C}_3\text{H}_7\text{OH}$	67-63-0	Liquid
Zinc Stearate	$\text{Zn}(\text{C}_{18}\text{H}_{35}\text{O}_2)_2$	557-05-1	Solid

**Table 8-1d. Process Chemicals in the Laboratories**

<b>CHEMICAL</b>			
<b>Name</b>	<b>Formula</b>	<b>CAS Number</b>	<b>STATE</b>
Aluminum Nitrate	$\text{Al}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$	13473-90-0	Liquid
Argon-Hydrogen	95% Ar; 5% $\text{H}_2$	N/A	Gas
Chromic (III) Acid	$\text{CrO}_3$	7738-94-5	Liquid
Ferrous sulfate	$\text{FeSO}_4$	7720-78-7	Liquid
Fluorine	$\text{F}$	7782-41-4	Liquid
Hydrofluoric Acid	$\text{HF}$	7664-39-3	Liquid
Hydrochloric Acid	$\text{HCl}$	7647-01-0	Liquid
Iron	$\text{Fe}$	7439-89-6	Liquid
Manganous Sulfate	$\text{MnSO}_4$	7785-87-7	Liquid*
Potassium Permanganate	$\text{KMnO}_4$	7722-64-7	Liquid
Silver Oxide	$\text{Ag}_2\text{O}$	20667-12-3	Liquid
Sodium	$\text{Na}$	7440-23-5	Liquid
Sodium Nitrite	$\text{NaNO}_2$	7632-00-0	Liquid
Sulfuric Acid	$\text{H}_2\text{SO}_4$	7664-93-9	Liquid
Sulfamic Acid	$\text{HSO}_3\text{NH}_2$	5329-14-6	Liquid
Thenoyl TrifluoroAcetone	$\text{C}_8\text{H}_5\text{F}_3\text{O}_2\text{S}$	326-91-0	Liquid
Xylene	$\text{C}_6\text{H}_4(\text{CH}_3)_2$	1330-20-7	Liquid

**Table 8-1e. Process Gases in the Gas Storage Area (GSA)**

<b>CHEMICAL</b>			
<b>Name</b>	<b>Formula</b>	<b>CAS Number</b>	<b>STATE</b>
Argon	Ar	7440-37-1	Liquid/ Gas
Argon-Hydrogen	95% Ar; 5% H <sub>2</sub>	N/A	Gas
Argon-Methane (P10)	90% Ar; 10% CH <sub>4</sub>	N/A	Gas
Helium	He	7440-59-7	Gas
Hydrogen	H <sub>2</sub>	N/A	Gas
Nitrogen	N <sub>2</sub>	7727-37-9	Gas
Oxygen	O <sub>2</sub>	N/A	Gas

**Table 8-2a. Chemicals and Chemical Tanks or Containers in the BRP, BAP, and BMP**

Chemical	Form	Symbol, Usage	Concentration		BRP		BAP		BMP
			Quantity	Units	Tank	Capacity (gal, U.N.O.)	Tank	Capacity (gal, U.N.O.)	
Aluminum Nitrate	L	Al(NO <sub>3</sub> ) <sub>3</sub> * 9H <sub>2</sub> O	1	g(Al)/l	N/A	N/A	RAN-TK1480	6	N/A
Azodicarbonamide	S	poreformer	100	%	N/A	N/A	N/A	N/A	1.2-kg (bag)
	S	poreformer	100	%	N/A	N/A	N/A	N/A	4-L (hopper)
Diluent (Note 1)	L	diluent	100	%	Tote Tank	180	N/A	N/A	N/A
	L	TBP + diluent	70	%	N/A	N/A	RTP-TK1020	30	N/A
	L	diluent	100	%	RDO-TK1000	80	RDO-TK1005	50	N/A
Hydrazine Monohydrate and Hydrazine Nitrate	L	N <sub>2</sub> H <sub>4</sub> -(H <sub>2</sub> O)	35	%	Tote Tank	126	N/A	N/A	N/A
	L	N <sub>2</sub> H <sub>4</sub> -H <sub>2</sub> O	35	%	RHZ-TK1150	80	N/A	N/A	N/A
	L	N <sub>2</sub> H <sub>4</sub> -HNO <sub>3</sub>	4	M	RHZ-REV1160	15	N/A	N/A	N/A
	L	N <sub>2</sub> H <sub>4</sub> -HNO <sub>3</sub>	4	M	RHZ-REV1170	15	N/A	N/A	N/A
	L	N <sub>2</sub> H <sub>4</sub> -HNO <sub>3</sub>	4	M	RHZ-REV1180	30	N/A	N/A	N/A
	L	N <sub>2</sub> H <sub>4</sub> -HNO <sub>3</sub>	4	M	RHZ-TK1181	5	N/A	N/A	N/A
Hydrazine and Sodium Hydroxide	L	N <sub>2</sub> H <sub>4</sub> -NaOH	0.16	N	RHZ-TK1182	384	RHZ-TK1183	384	N/A
Hydrogen Peroxide	L	H <sub>2</sub> O <sub>2</sub>	35	%	Drums	TBD	N/A	N/A	N/A
	L	H <sub>2</sub> O <sub>2</sub>	10	%	RHP-TK1200	40	RHP-TK1205	40	N/A

Table 8-2a. Chemicals and Chemical Tanks or Containers in the BRP, BAP, and BMP (continued)

Chemical	Form	Symbol, Usage	Concentration		BRP		BAP		BMP
			Quantity	Units	Tank	Capacity (gal, U.N.O.)	Tank	Capacity (gal, U.N.O.)	
Hydroxylamine Nitrate	L	HAN	1.9	M	Tote Tank	180	N/A	N/A	N/A
	L	HAN	1.9	M	RHN-TK1060	200	RHN-TK1090	55	N/A
Hydroxylamine Nitrate and Hydrazine	L	HAN-N <sub>2</sub> H <sub>2</sub> -HNO <sub>3</sub>	0.15	M	RHN-TK1070	627	RHN-TK1080	320	N/A
	L	HAN-N <sub>2</sub> H <sub>4</sub> - HNO <sub>3</sub>	0.15	M	N/A	N/A	RHN-TK1081	5	N/A
	L	HAN-N <sub>2</sub> H <sub>4</sub> - HNO <sub>3</sub>	0.15	M	RHN-TK1110	150 Note 2	RHN-TK1082	60 Note 2	N/A
Isopropanol	L	(CH <sub>3</sub> ) <sub>2</sub> CHOH	100	%	N/A	N/A	N/A	N/A	0.5-L (bottle)
	L	Mn <sup>+2</sup>	1	%	N/A	N/A	Bottles	TBD	N/A
Manganese Nitrate	L	HNO <sub>3</sub> -Mn <sup>+2</sup>	0.01	M	N/A	N/A	RMN-TK1050	15	N/A
	L	HNO <sub>3</sub> -Mn <sup>+2</sup>	0.01	M	N/A	N/A	RMN-TK1051	5	N/A
	L	HNO <sub>3</sub> -Mn <sup>+2</sup>	0.011	M	N/A	N/A	KCD-TK4000	100 liters	N/A
	L	HNO <sub>3</sub> -Mn <sup>+2</sup>	0.011	M	N/A	N/A	KCD-TK4100	100 liters	N/A
	L	HNO <sub>3</sub> -Mn <sup>+2</sup>	0.011	M	N/A	N/A	KCD-TK4200	100 liters	N/A
	L	HNO <sub>3</sub> -Mn <sup>+2</sup>	9.90E-05	M	N/A	N/A	KCD-TK1000	1000 liters	N/A
	L	HNO <sub>3</sub> -Mn <sup>+2</sup>	9.90E-05	M	N/A	N/A	KCD-TK1500	1000 liters	N/A
Nitric Acid (Note 1)	L	HNO <sub>3</sub> -Mn <sup>+2</sup>	9.90E-05	M	N/A	N/A	KCD-TK2000	1000 liters	N/A
	L	HNO <sub>3</sub>	13.6	N	Tote Tank	126	N/A	N/A	N/A

Table 8-2a. Chemicals and Chemical Tanks or Containers in the BRP, BAP, and BMP (continued)

Chemical	Form	Symbol, Usage	Concentration		BRP		BAP		BMP
			Quantity	Units	Tank	Capacity (gal, U.N.O.)	Tank	Capacity (gal, U.N.O.)	
	L	HNO <sub>3</sub>	13.6	N	RNA-TK1260	142	RNA-TK1265	161	N/A
	L	HNO <sub>3</sub>	13.6	N	RNA-TK1261	5	N/A	N/A	N/A
	L	HNO <sub>3</sub>	13.6	N	N/A	N/A	RNA-TK1262	5	N/A
	L	HNO <sub>3</sub>	13.6	N	N/A	N/A	RNA-TK1263	5	N/A
	L	HNO <sub>3</sub>	13.6	N	N/A	N/A	KDD-TK1500	60 liters	N/A
	L	HNO <sub>3</sub>	13.6	N	N/A	N/A	KDD-TK2500	60 liters	N/A
	L	HNO <sub>3</sub>	13.6	N	N/A	N/A	KPC-TK4000	500 liters	N/A
	L	HNO <sub>3</sub>	13.6	N	N/A	N/A	KPC-TK4500	500 liters	N/A
	L	HNO <sub>3</sub>	6	N	N/A	N/A	RNA-TK1330	8	N/A
	L	HNO <sub>3</sub>	2.1	N	N/A	N/A	KPC-TK1000	5000 liters	
	L	HNO <sub>3</sub>	1.5	N	N/A	N/A	RNA-TK1030	350	N/A
	L	HNO <sub>3</sub>	1.5	N	N/A	N/A	RNA-TK1040	400	N/A
	L	HNO <sub>3</sub>	1.5	N	N/A	N/A	RNA-TK1041	5	N/A
	L	HNO <sub>3</sub>	Variable	N	RNA-TK1421	150 Note 2	N/A	N/A	N/A



Table 8-2a. Chemicals and Chemical Tanks or Containers in the BRP, BAP, and BMP (continued)

Chemical	Form	Symbol, Usage	Concentration		BRP		BAP		BMP
			Quantity	Units	Tank	Capacity (gal, U.N.O.)	Tank	Capacity (gal, U.N.O.)	
Nitrogen Tetroxide	L	N <sub>2</sub> O <sub>4</sub>	100	%	Cylinders	1 Ton (240 gal)	N/A	N/A	N/A
	L	N <sub>2</sub> O <sub>4</sub>	100	%	GNO-TK1300	1 Ton (240 gal)	N/A	N/A	N/A
	L	N <sub>2</sub> O <sub>4</sub>	100	%	GNO-TK1310	1 Ton (240 gal)	N/A	N/A	N/A
Oxalic Acid	S	H <sub>2</sub> C <sub>2</sub> O <sub>4</sub>	100	%	Bags and HOPPER 1120	TBD	N/A	N/A	N/A
	L	H <sub>2</sub> C <sub>2</sub> O <sub>4</sub>	0.7	M	ROA-TK1120	416	ROA-TK1130	459	N/A
	L	H <sub>2</sub> C <sub>2</sub> O <sub>4</sub>	0.7	M	N/A	N/A	ROA-TK1131	5	N/A
	L	H <sub>2</sub> C <sub>2</sub> O <sub>4</sub> -HNO <sub>3</sub>	0.05	M	N/A	N/A	ROA-TK1140	162	N/A
	L	H <sub>2</sub> C <sub>2</sub> O <sub>4</sub> -HNO <sub>3</sub>	0.05	M	N/A	N/A	ROA-TK1141	5	N/A
Plutonium Dioxide (polished)	S	PuO <sub>2</sub>	100	%	N/A	N/A	KCC-Pot	2.2 kg	997.5 kg (2.5 kg /pot 399 pots)
	S	PuO <sub>2</sub>	100	%	N/A	N/A	KCB-HPR1000	17.6 kg	N/A
	S	PuO <sub>2</sub>	100	%	N/A	N/A	KCB-HPR2000	17.6 kg	N/A
Plutonium Dioxide (unpolished)	S	PuO <sub>2</sub>	100	%	N/A	N/A	KDA-HPR9000	6 kg	8640 kg (5 kg (max)/ container*1728 containers)
	S	PuO <sub>2</sub>	100	%	N/A	N/A	KDA-HPR9100	6 kg	N/A
Plutonium Oxalate	L	Pu(C <sub>2</sub> O <sub>4</sub> ) <sub>2</sub>	25.1	g(Pu)/liter	N/A	N/A	KCA-PREC5000	5	N/A
	L	Pu(C <sub>2</sub> O <sub>4</sub> ) <sub>2</sub>	25.1	g(Pu)/liter	N/A	N/A	KCA-PREC6000	5	N/A

Table 8-2a. Chemicals and Chemical Tanks or Containers in the BRP, BAP, and BMP (continued)

Chemical	Form	Symbol, Usage	Concentration		BRP		BAP		BMP
			Quantity	Units	Tank	Capacity (gal, U.N.O.)	Tank	Capacity (gal, U.N.O.)	
Plutonium Nitrate	L	$\text{Pu}(\text{NO}_3)_3$ + $\text{Pu}(\text{NO}_3)_4$	40	g(Pu)/liter	N/A	N/A	KPA-TK1000	1000 liters	N/A
	L	$\text{Pu}(\text{NO}_3)_4$	39.9	g(Pu)/liter	N/A	N/A	KPA-TK7000	1000 liters	N/A
	L	$\text{Pu}(\text{NO}_3)_4$	40.9	g(Pu)/liter	N/A	N/A	KDB-TK7000	700 liters	N/A
	L	$\text{Pu}(\text{NO}_3)_4$	40.9	g(Pu)/liter	N/A	N/A	KDB-TK5000	400 liters	N/A
	L	$\text{Pu}(\text{NO}_3)_4$	40.9	g(Pu)/liter	N/A	N/A	KDB-TK6000	400 liters	N/A
	L	$\text{PuO}_2(\text{NO}_3)_2$	229	g(Pu)/liter	N/A	N/A	KDB-EZR1000	52 liters	N/A
	L	$\text{PuO}_2(\text{NO}_3)_2$	229	g(Pu)/liter	N/A	N/A	KDB-EZR2000	52 liters	N/A
	L	$\text{PuO}_2(\text{NO}_3)_2$ + $\text{Pu}(\text{NO}_3)_4$	95.2	g(Pu)/liter	N/A	N/A	KDB-TK3000	150 liters	N/A
	L	$\text{PuO}_2(\text{NO}_3)_2$ + $\text{Pu}(\text{NO}_3)_4$	95.2 (R25)	g(Pu)/liter	N/A	N/A	KDB-TK4000	150 liters	N/A
	L	$\text{Pu}(\text{NO}_3)_4$	39.9 (R25)	g(Pu)/liter	N/A	N/A	KCA-TK1000	600 liters	N/A
	L	$\text{Pu}(\text{NO}_3)_4$	39.9 (R25)	g(Pu)/liter	N/A	N/A	KCA-TK2000	600 liters	N/A
	L	$\text{AgNO}_3$	2	N	N/A	N/A	Bottles	TBD	N/A
Silver Nitrate	L	$\text{Ag}^+ \cdot \text{HNO}_3$	1	N	N/A	N/A	RSN-TK1210	30	N/A

Table 8-2a. Chemicals and Chemical Tanks or Containers in the BRP, BAP, and BMP (continued)

Chemical	Form	Symbol, Usage	Concentration		BRP		BAP		BMP
			Quantity	Units	Tank	Capacity (gal, U.N.O.)	Tank	Capacity (gal, U.N.O.)	
Sodium Carbonate	S	Na <sub>2</sub> CO <sub>3</sub>	100	%	Bags	TBD	N/A	N/A	N/A
	L	Na <sub>2</sub> CO <sub>3</sub>	0.3	M	RSC-TK1240	46	RSC-TK1250	46	N/A
Sodium Hydroxide	L	NaOH, Soda	10	N	Tote Tank	126	Bottles	TBD	N/A
	L	NaOH, Soda	0.1	N	N/A	N/A	RSH-TK1280	40	N/A
	L	NaOH, Soda	0.1	N	N/A	N/A	RSH-TK1290	40	N/A
Tributyl Phosphate	L	solvent, TBP	100	%	Tote Tank	126	RTP-TK1011	5	N/A
	L	solvent, TBP	100	%	RTP-TK1010	80	RTP-TK1015	40	N/A
	L	TBP+diluent	30	%	N/A	N/A	KPB-TK2000	500 liters	N/A
	L	TBP+diluent	30	%	N/A	N/A	RTP-TK1020	30	N/A
Uranium Dioxide	S	UO <sub>2</sub>	100	%	N/A	N/A	N/A	N/A	1 drum 200 kg (max) /drum
	S	UO <sub>2</sub>	100	%	N/A	N/A	N/A	N/A	1 drum 200 kg (max) /drum
	S	UO <sub>2</sub>	100	%	N/A	N/A	N/A	N/A	2 drums 200 kg (max) /drum

Table 8-2a. Chemicals and Chemical Tanks or Containers in the BRP, BAP, and BMP (continued)

Chemical	Form	Symbol, Usage	Concentration		BRP		BAP		BMP
			Quantity	Units	Tank	Capacity (gal, U.N.O.)	Tank	Capacity (gal, U.N.O.)	
Uranyl Nitrate	L	UO <sub>2</sub> (NO <sub>3</sub> ) <sub>2</sub>	0.64	g(U)/liter	N/A	N/A	KDB-TK5000	400 liters	N/A
	L	UO <sub>2</sub> (NO <sub>3</sub> ) <sub>2</sub>	0.64	g(U)/liter	N/A	N/A	KDB-TK6000	400 liters	N/A
	L	UO <sub>2</sub> (NO <sub>3</sub> ) <sub>2</sub>	0.64	g(U)/liter	N/A	N/A	KDB-TK7000	700 liters	N/A
	L	UO <sub>2</sub> (NO <sub>3</sub> ) <sub>2</sub>	200	g(U)/liter	N/A	N/A	KDC-TK2000	300 liters	N/A
	L	UO <sub>2</sub> (NO <sub>3</sub> ) <sub>2</sub>	200	g(U)/liter	N/A	N/A	KDC-TK4000	750 liters	N/A
Zinc Stearate	S	Dry lubricant	100	%	N/A	N/A	N/A	N/A	TBD
	S	Dry lubricant	100	%	N/A	N/A	N/A	N/A	16-L (hopper)
Zirconium Nitrate	L	Zr(NO <sub>3</sub> ) <sub>2</sub> *5H <sub>2</sub> O	10	g(Zr)/liter	TBD	40	TBD	40	N/A

Table 8-2a Notes:

1. Diluent and nitric acid are recovered in the Aqueous Polishing process. The preparation of these reagents will be drastically reduced, once the AP process is in operation, as recovered reagents will become available.
2. Drain tanks are normally empty.

**Table 8-2b. Anticipated Chemical Inventory in Secured Warehouse**

<b>Chemical</b>	<b>Total Quantity Anticipated in Secured Warehouse</b>
Uranium Dioxide (Powder)	37.5 MT (200 drums @ 187.5 kg/drum)

**Table 8-2c. Anticipated Chemical Inventory in the Laboratories**

<b>Chemical</b>	<b>Total Quantity Anticipated in Laboratories</b>
Aluminum Nitrate	Less than 10 kilograms
Argon-Hydrogen (95% Ar 5% H)	No more than one cylinder (300 cu ft) per lab
Argon-Methane (P10)	(Piped into laboratories)
Chromic (III) Acid	Less than 10 kilograms
Ferrous sulfate	Less than 10 kilograms
Fluorine	Less than 10 kilograms
Hydrofluoric Acid	Less than 10 kilograms
Hydrochloric Acid	Less than 10 kilograms
Iron	Less than 10 kilograms
Manganous Sulfate	Less than 10 kilograms
Potassium Permanganate	Less than 10 kilograms
Silver Oxide	Less than 10 kilograms
Sodium	Less than 10 kilograms
Sodium Nitrite	Less than 1 kilogram
Sulfuric Acid	Less than 10 kilograms
Sulfamic Acid	Less than 10 kilograms
Thenoyl TrifluoroAcetone	Less than 10 kilograms
Xylene (Lab)	Less than 10 kilograms

**Table 8-2d. Anticipated Gas Storage Area Inventory**

<b>Chemical</b>	<b>Anticipated Gas Storage Area Inventory</b>
Argon	Two (2) 3,000 gallon liquefied gas storage tanks
Argon-Hydrogen	One tube trailer - 56,000 scf
Argon-Methane (P10)	One tube trailer - 45,000 scf
Helium	One large tube trailer – 140,494 scf
Hydrogen	Two (2) tube trailers – 43,000 scf each
Nitrogen	Two (2) buffer tanks – 1209 and 11 cu ft Liquid nitrogen storage tank – 9000 gallons
Oxygen	Two (2) cylinders – 6250 scf each

**Table 8-3. Reaction Products of the Aqueous Polishing Process**

**(Normal Operations)**

<b>Chemical</b>	<b>Formula</b>	<b>Comment</b>
Alkaline Wastes (including dibutyl phosphate and monobutyl phosphate)	Various	Alkaline wastes are generated in the Solvent Recovery Unit as a result of washing solvent with sodium carbonate and sodium hydroxide solutions (Note 3)
Carbon Dioxide	CO <sub>2</sub>	Reaction product when plutonium oxalate is transformed into PuO <sub>2</sub> in the Oxalic Precipitation and Oxidation Unit (Note 3)
Carbon Monoxide	CO	Reaction product when plutonium oxalate is transformed into PuO <sub>2</sub> in the Oxalic Precipitation and Oxidation Unit (trace quantities only) (Note 3)
Chlorine	Cl <sub>2</sub>	Reaction product from dissolution of AFS material in the Dechlorination Dissolution Unit (subsequently treated in the dechlorination scrubbing column) (Note 2)
Hydrogen	H <sub>2</sub>	Produced from radiolysis and electrolysis reaction (Note 4)
Nitrogen Oxides	NO <sub>x</sub>	Reaction product of UO <sub>2</sub> dissolution in the UO <sub>2</sub> Dissolution Unit (subsequently scrubbed in the NO <sub>x</sub> scrubbing columns of the UO <sub>2</sub> Dissolution Unit and Offgas Treatment Unit) (Note 2)
Nitrogen	N <sub>2</sub>	Reaction product of several reactions in the Purification Cycle oxidation column; reaction product in dechlorination scrubbing column of the Dechlorination Dissolution Unit (Note 3)
Nitric Acid	HNO <sub>3</sub>	Reformed in NO <sub>x</sub> scrubbing columns (UO <sub>2</sub> Dissolution Unit and Offgas Treatment Unit) (Note 1)
Nitrous Acid	HNO <sub>2</sub>	Always present in nitric acid solutions (Note 3)



**Table 8-3. Reaction Products of the Aqueous Polishing Process (continued)**  
**(Normal Operations)**

<b>Chemical</b>	<b>Formula</b>	<b>Comment</b>
Nitrous Oxide	$N_2O$	Reaction product of several reactions in the Purification Cycle oxidation column (Note 2)
Oxygen	$O_2$	Reaction product of hydrogen peroxide decomposition during $PuO_2$ dissolution in the Dissolution Unit (Note 3)
Plutonium Dioxide	$PuO_2$	Reformed in the calcining furnace of the Oxalic Precipitation and Oxidation Unit from the plutonium oxalate feed (Note 1)
Plutonium Oxalate	$Pu(C_2O_4)_2$	Precipitated in the Oxalic Precipitation and Oxidation Unit from the reaction of plutonium nitrate with oxalic acid (Note 1)
Plutonium (III, IV, VI) Nitrate	$Pu(NO_3)_3$ , $Pu(NO_3)_4$ , $PuO_2(NO_3)_2$	Plutonium (VI) Nitrate - formed from the dissolution of plutonium dioxide in the Dissolution Unit and in the evaporator of the Oxalic Mother Liquor Recovery Unit (Note 1)  Plutonium (IV) Nitrate - formed from the addition of hydrogen peroxide to the plutonium (VI) nitrate solution in the Dissolution Unit (Note 1)  Plutonium (III) Nitrate - formed from the reduction of plutonium (IV) nitrate solution with HAN in the Purification Unit (Note 1)
Sodium Chloride	$NaCl$	Reaction product in the dechlorination scrubbing column of the Dechlorination Dissolution Unit (Note 3)
Uranyl Nitrate	$UO_2(NO_3)_2$	Formed from the dissolution of uranium dioxide in nitric acid (Note 1)

**Table 8-3. Reaction Products of the Aqueous Polishing Process (continued)**  
**(Normal Operations)**

<b>Chemical</b>	<b>Formula</b>	<b>Comment</b>
Water	H <sub>2</sub> O	Reaction product of several reactions in the Purification Cycle oxidation column; reaction product of hydrogen peroxide decomposition during PuO <sub>2</sub> dissolution in the Dissolution Unit; Reaction product of UO <sub>2</sub> dissolution reaction in the UO <sub>2</sub> Dissolution Unit (Note 3)

**Table 8-3 Notes:**

1. Chemical consequence analyses have been performed for nitric acid, uranyl nitrate and the plutonium compounds. Inventories are identified in Table 8-2a.
2. Chemical consequence analyses have been performed for chlorine and nitrogen oxides.
3. Because of low rate of production and/or lack of toxicity, inventories are not quantified for the purposes of calculating chemical consequences to the site worker or the public from spills or releases.
4. The generation of hydrogen is considered in the design of the scavenging air system.

**Table 8-4. Process Chemical Hazardous Characteristics and Incompatibilities**

Form	Chemical	Corrosive	Flammable	Explosive	Chemical Burn	Toxic	Incompatibilities
Liquid	Nitric Acid (13.6N)	x			x	x	Organics, Hydrogen Peroxide, Hydroxylamine Nitrate, Hydrazine Monohydrate, Sodium Carbonate, Sodium Hydroxide
	Hydrogen Peroxide			x	x	x	Organics, Nitric Acid, Manganese (metal), Hydrazine, Sodium Carbonate, Metallic Salts
	Tributyl Phosphate (solvent)		x	x	x	x	Ammonia, Nitric Acid, Oxidizing Agents, Strong Bases
	Diluent (C10-C13 isoalkane)		x	x		x	Oxidizing Agents, Oxygen
	Sodium Carbonate (also present as a solid)					x	Aluminum, Acids, Hydrogen Peroxide
	Demineralized Water						
	Hydroxylamine Nitrate (HAN)	x		x	x	x	Bichromate and Permanganate of Potassium, Copper Sulfate, Zinc, Strong Oxidizers, Strong Reducing Agents, Nitric Acid, Combustible Materials
	Hydrazine Monohydrate	x		x	x	x	Oxidizing Agents (Nitric Acid), Metals, Asbestos
	Sodium Hydroxide	x			x	x	Acids, Aluminum and other metals, Organic Halogens (especially Trichlorethylene), Sugars
	Aluminum Nitrate	x			x	x	Combustible Materials, Strong Reducing Agents, Metals, Water
	Hydrazine Nitrate	x			x	x	Acids, Strong Oxidizers, Metal Salts
	Isopropanol		x			x	Oxidizing Agents
	Zirconium Nitrate	x			x	x	Combustible Materials, Strong Reducing Agents, Metals
Gas	Dinitrogen Tetroxide/Nitrogen Dioxide	x		x	x	x	Reducing Agents, Organics, Metals
	Helium						
	Argon						
	Hydrogen		x	x			
	Oxygen					x	Organics
Solid	Silver Nitrate (also present as liquid)	x		x	x	x	Ammonia, Carbonates, Chlorides
	Manganese Nitrate (also present as liquid)	x		x	x	x	Strong Reducing Agents, Combustible Materials
	Oxalic Acid (also present as liquid)				x	x	Silver, Sodium Chloride, Sodium Hypochlorite
	Azodicarbonamide						Strong Oxidizing Agents
	Zinc Stearate		x			x	Strong Oxidizing Agents, Acids

**Table 8-5. TEELs Used as Chemical Limits for Chemicals at the  
MFFF (Note 1)  
(mg/m<sup>3</sup>)**

<b>Name</b>	<b>TEEL-1</b>	<b>TEEL-2</b>	<b>TEEL-3</b>
Aluminum Nitrate	15	15	500
Azodicarbonamide	125	500	500
Chromic (III) Acid	1	2.5	25
Chlorine	3	7.5	60
Diluent (C10-C13 Isoalkanes)	5	35	200
Ferrous sulfate	7.5	12.5	350
Fluorine	0.75	7.5	30
Hydrazine Monohydrate	0.0075	0.06	50
Hydrazine Nitrate	3	5	5
Hydrofluoric Acid	1.5	15	40
Hydrochloric Acid	4	30	200
Hydrogen Peroxide	12.5	60	125
Hydroxylamine Nitrate	15	26	125
Iron	30	50	500
Isopropanol	1000	1000	5000
Manganese Nitrate	10	15	500
Manganous Sulfate	7.5	12.5	500
Nitric Acid	2.5	15	200
Nitric Oxide	30	30	125
Nitrogen Dioxide	7.5	7.5	35
Nitrogen Tetroxide	15	15	75
Oxalic Acid	2	5	500
Potassium Permanganate	7.5	15	125
Silver Nitrate	0.03	0.05	10
Silver Oxide	30	50	75
Sodium	0.5	5	50
Sodium Carbonate	30	50	500
Sodium Hydroxide	0.5	5	50
Sodium Nitrite	0.125	1	60

**Table 8-5. TEELs Used as Chemical Limits for Chemicals at the  
MFFF (Note 1) (continued)**  
(mg/m<sup>3</sup>)

Name	TEEL-1	TEEL-2	TEEL-3
Sulfuric Acid	2	10	30
Sulfamic Acid	40	250	500
Thenoyl TrifluoroAcetone	3.5	25	125
Tributyl Phosphate	6	10	300
Uranium Dioxide	0.6	1	10
Uranyl Nitrate	1	1	10
Xylene	600	750	4000
Zinc Stearate	30	50	400
Zirconium nitrate	35	35	50

Table 8-5 Notes:

1. Temporary Emergency Exposure Limits (TEELs), Revision 18, are derived from approved methodologies developed by Department of Energy Subcommittee on Consequence Assessment & Protective Actions (SCAPA) and are identified in WSMS-SAE-02-0001.

**Table 8-6. Application of Chemical Limits to  
Qualitative Chemical Consequence Categories**

<b>Consequence Category</b>	<b>Worker</b>	<b>Public</b>
High	Concentration $\geq$ TEEL-3	Concentration $\geq$ TEEL-2
Intermediate	TEEL-3 > Concentration $\geq$ TEEL-2	TEEL-2 > Concentration $\geq$ TEEL-1
Low	TEEL-2 > Concentration	TEEL-1 > Concentration

**Table 8-7. Combustible Characteristics of Chemicals in the AP Area**

<b>Combustible</b>	<b>Location</b>	<b>Flash Point (°C)</b>
Solvent + Diluent (30/70)%	Purification Cycle and Solvent Recovery Cycle	> 55
Solvent (TBP)	Storage Tanks and Solvent Recovery	146
Diluent	Pulsed Column, Diluent Washing and Storage	>55
Oil & Hydraulic Fluid	Building	>100

**Table 8-8. Nomenclature of Chemical Species**

Name	Abbrev.	Formula
Tri-n-butyl phosphate	TBP	$(C_4H_9O)_3PO$
Dibutyl phosphate	DBP	$(C_4H_9O)_2PO(OH)$
Monobutyl phosphate	MBP	$(C_4H_9O)PO(OH)_2$
Butyl alcohol or Butanol	BuOH	$C_4H_9OH$
Butyl nitrate	BuNO <sub>3</sub>	$C_4H_9NO_3$
Butyric acid		$C_3H_7COOH$
Propionic acid		$C_2H_5COOH$
Acetic acid		$CH_3COOH$
Phosphoric acid		$H_3PO_4$
Butene		$C_4H_8$



## **Figures**

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Flammability Limits H<sub>2</sub>-Air vs. Argon Concentration  
 Chemsafe (C) DECHEMAe.V.14.10.2002

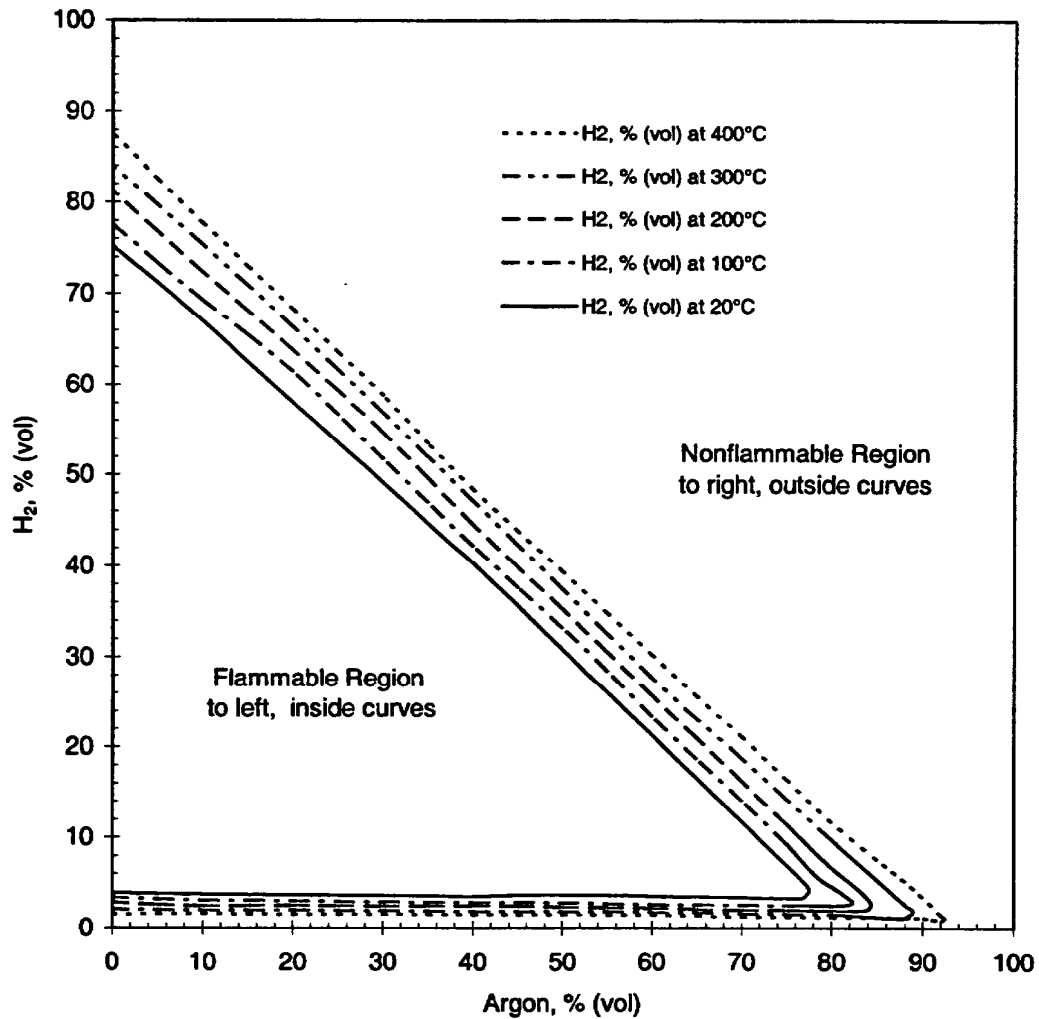
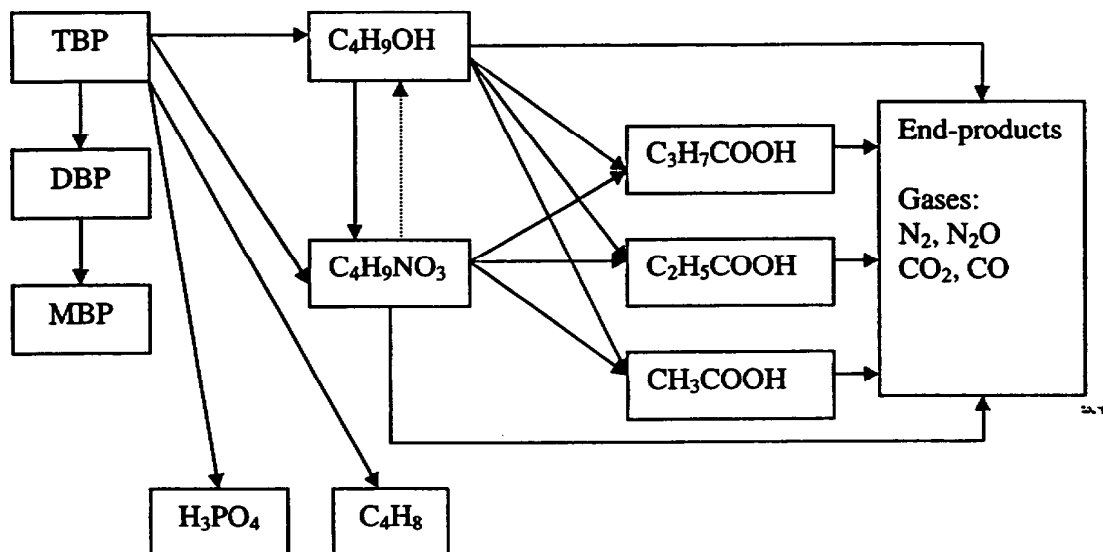


Figure 8.5-1. Flammability Limits H<sub>2</sub>-Air vs Argon Concentration

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**Figure 8.5-2. Oxidative Reaction Scheme of TBP Degradation in Contact with Nitric Acid**

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